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CONSTRUCTION ENGINEERING RESEARCH LAB (ARMY) CHAMPAIGN IL F/G 13/2
EVALUATION OF ROTATING BIOLOGICAL CONTACTOR TECHNOLOGY FOR CIVI--ETC(U)
APR 82 E D SMITH, C P POON, J CULLINANE
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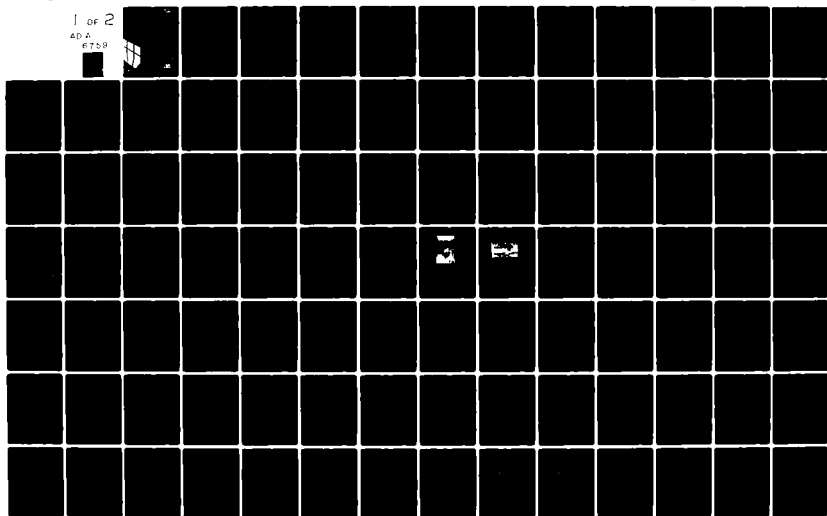
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TECHNICAL REPORT N-126
April 1982

EVALUATION OF ROTATING BIOLOGICAL CONTACTOR
TECHNOLOGY FOR CIVIL WORKS RECREATIONAL AREAS

by
Ed D. Smith
Calvin P. C. Poon
John Cullinane
Glenn Hawkins

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RECREATIONAL AREAS

APRIL 1982

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER CERL-TR-N-126	2. GOVT ACCESSION NO. 1.3-10-1050	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) EVALUATION OF ROTATING BIOLOGICAL CONTACTOR TECHNOLOGY FOR CIVIL WORKS RECREATIONAL AREAS		5. TYPE OF REPORT & PERIOD COVERED FINAL
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Ed D. Smith Calvin P. C. Poon John Cullinane Glen Hawkins		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. ARMY CONSTRUCTION ENGINEERING RESEARCH LABORATORY P.O. Box 4005, Champaign, IL 61820		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS CWIS 31734
11. CONTROLLING OFFICE NAME AND ADDRESS		12. REPORT DATE April 1982
		13. NUMBER OF PAGES 100
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES Copies are obtainable from the National Technical Information Service Springfield, VA 22161		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) sewage treatment rotating biological contactors recreation		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The objective of this study was to investigate the applicability of rotating biological contactor (RBC) technology for treating wastewaters generated at typical U.S. Army Corps of Engineers recreation areas. This report outlines selection criteria for civil works personnel who must decide whether to use RBCs, provides RBC case histories for use at Corps recreational areas, and presents guidance to ensure that RBC use is both economical and compatible with the Corps' needs.		

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These objectives were accomplished in four steps:

1. Corps district and division personnel, and pollution abatement engineers familiar with recreational area wastewaters were surveyed. Visits were made to Corps recreational areas, and to sites which were operated and maintained by various State and National Park Service districts, and which used RBC technology.
2. The literature on RBC technology was reviewed.
3. An evaluation and economic comparison were done for RBC technology and older treatment alternatives, such as package extended aeration, lagoons, septic tanks, leaching fields, oxidation ditches, and land treatment.
4. Preliminary design guidance and a procedure for selecting RBC technology were developed for Corps recreational areas.

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FOREWORD

This investigation was performed by the Environmental Division (EN) of the U.S. Army Construction Engineering Research Laboratory (CERL) for the Directorate of Civil Works, Office of the Chief of Engineers (OCE) under Project CWIS 31734. Dr. R. K. Jain is Chief of EN. The OCE Technical Monitor was Mr. Glenn Hawkins, DAEN-CWE-BU.

COL L. J. Circeo is Commander and Director of CERL, and Dr. L. R. Shaffer is Technical Director.

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CONTENTS

	<u>Page</u>
DD FORM 1473	1
FOREWORD	3
LIST OF FIGURES AND TABLES	6
1 INTRODUCTION.....	9
Background	9
Objective	10
Approach	10
Outline of This Report	10
2 SURVEY SUMMARY AND SCENARIO DESCRIPTION.....	11
Site Usage	11
Sewage Flow Characteristics	11
Sewage Influent Characteristics	13
Sewage Effluent Characteristics and Effluent Quality Standards	15
Operation and Maintenance of Treatment Facilities	15
Cost of Treatment Plants	17
Choosing a Treatment Technology	21
States' Survey	25
Federal Highway Administration Survey	25
National Park Service Survey	25
Summary of Survey Results	27
Corps Recreational Area Scenario	27
3 LITERATURE REVIEW AND DOCUMENTATION OF EXISTING RBC PLANTS IN RECREATIONAL AREAS.....	30
Literature Review	30
Existing RBC Plants in Recreational Areas	35
4 COMPARISONS OF RBC AND OTHER TREATMENT TECHNOLOGIES.....	59
Design of a Typical Corps Recreational Area Sewage Treatment Facility	59
Design Criteria Applicable to All Technologies	59
Extended Aeration With Sand Filters	61
Facultative/Aerated Lagoon With Sand Filters	63
Facultative/Aerated Lagoon With Land Treatment (Spray Irrigation)	68
Oxidation Ditch With Sand Filters	69
Rotating Biological Contactor With Sand Filters	73
Septic Tank/Leaching Field	75
Cost Comparison of Alternatives	75
Characteristics of RBC Systems for Corps Recreational Areas	76

CONTENTS (Cont'd)

	<u>Page</u>
5 RBC TECHNOLOGY SELECTION AND DESIGN GUIDANCE FOR	
CORPS RECREATIONAL AREAS.....	87
Comparison of RBC With Other Treatment Technologies	87
Selecting RBC Systems	88
Step-by-Step Procedure for RBC Design	88
6 SUMMARY.....	93
METRIC CONVERSION FACTORS	94
APPENDIX: Survey Questionnaire Sent to Corps	
District Offices	95
DISTRIBUTION	

FIGURES

<u>Number</u>		<u>Page</u>
1	Schematic Diagram of Camp Horseshoe Bio-Disc Plant	36
2	Boldt Castle Treatment Process	39
3	Albert Lea Information Center RBC	43
4	Chlorination Tank at Indiana Dunes National Lakeshore	46
5	The RBC at Indiana Dunes National Lakeshore	47
6	Kentucky Horse Park Wastewater Treatment Plant	48
7	Bolar Mountain Recreational Area RBC Plant Layout	53
8	Biological Unit	54
9	Biological Treatment Section, and Splitter Box and Weir Section	55
10	Sand Filtration System	56
11	Chlorination System	57
12	Extended Aeration With Sand Filters	62
13	Facultative/Aerated Lagoon With Sand Filters	64
14	Size of Aerated Lagoon	68
15	Facultative/Aerated Lagoon With Land Treatment	68
16	Oxidation Ditch With Sand Filters	71
17	Capacity of Oxidation Ditch	72
18	RBC With Sand Filters	73
19	Design Curves for BOD Removal: Autotrol	89
20	Design Curves for BOD Removal: Hormel	89
21	Design Curves for NH ₃ -N Removal: Autotrol	90
22	Design Curves for NH ₃ -N Removal: Hormel	90

TABLES

<u>Number</u>		<u>Page</u>
1	Corps District Offices	12
2	Flow Fluctuations at Corps Recreational Areas	13
3	Sewage Influent Characteristics	14
4	Effluent Characteristics in Corps Recreational Areas	16
5	Sewage Treatment Plant Operation and Maintenance in Corps Recreational Areas	18
6	System Operation and Maintenance Costs of Existing Sewage Treatment Plants in Corps Recreational Areas	20
7	Planning of Sites by Corps District Offices	22
8	Rationale for Treatment Technology Selection	23
9	State Recreational Area Wastewater Treatment Facilities	26
10	Plant Specifications	37
11	Design Values for Boldt Castle RBC System	40
12	Boldt Castle Wastewater Treatment Facility's Basis of Design	41
13	Results of Composite Sample	44
14	Boldt Castle Wastewater and Effluent Characteristics	45
15	Plant Unit Capacities and Criteria	49
16	Bolar Plant Unit Capacities and Criteria	58
17	Septic Tank/Leaching Field or Subsurface Sand Filters	60
18	Extended Aeration With Flow Equalization	61
19	Facultative/Aerated Lagoon With Sand Filter for Effluent Polishing	62
20	Oxidation Ditch	63
21	Land Treatment	64

TABLES (Cont'd)

<u>Number</u>		<u>Page</u>
22	RBC With a Septic Tank Serving Both Flow Equalization and Sludge Treatment	65
23	Design Summary: Extended Aeration With Sand Filters	66
24	Calculation of Storage Pond Capacity	70
25	Septic Tank/Leaching Field System	77
26	Extended Aeration/Sand Filters	78
27	Facultative/Aerated Lagoon and Sand Filters	79
28	Facultative/Aerated Lagoon and Spray Irrigation	80
29	Oxidation Ditch and Sand Filters	81
30	RBC and Sand Filters	82
31	Summary of Alternatives	83
32	Soluble BOD Loading Rates (Clow Corp.)	91
33	Nitrification Loading Rates, Clow Corp.	91

EVALUATION OF ROTATING BIOLOGICAL CONTACTOR TECHNOLOGY FOR CIVIL WORKS RECREATIONAL AREAS

1 INTRODUCTION

Background

The U.S. Army Corps of Engineers designs, builds, and operates wastewater treatment systems for its civil works projects, primarily those associated with the increasingly important recreation program. Over 438 million visitors used Corps recreation areas in 1978, so wastewater treatment is a major responsibility. The discharge of pollutants from recreation areas to receiving streams or lakes must meet National Pollutant Discharge Elimination System (NPDES) requirements.

Wastewater treatment is necessary both to comply with Public Law 95-200, and to maintain the aesthetic qualities of the bodies of water on recreation sites.¹ Wastewater treatment is particularly important in recreational areas because of the ultimate use of the receiving water for both primary and secondary contact recreation. Under present standards, major constituents of wastewater must meet effluent requirements of NPDES, i.e., biochemical oxygen demand (BOD), suspended solids (SS) and fecal coliform. Occasionally nitrogen, phosphorus, and dissolved oxygen are also requirements of the NPDES permit.

The number of visitors at recreation areas varies daily, weekly, and seasonally. Because wastewater production is proportional to recreation area usage, highly variable wastewater flows, which create operational problems, are characteristic of most of these areas.

Traditionally, wastewater at recreation areas has been treated by lagoons, package treatment plants, or land treatment systems. But treatment requirements are becoming more stringent, energy and labor costs are rising, and the amount of land that can be used for treatment is decreasing. It would be useful to investigate whether there are other alternative treatment processes which are easy to operate and can meet stringent regulatory requirements while handling variable flows, using minimal amounts of energy, and generating small quantities of residue for disposal.

The Office of the Chief of Engineers (OCE) asked the U.S. Army Construction Engineering Research Laboratory (CERL) to examine specifically the usefulness of rotating biological contactors (RBC) at Corps recreation areas and to compare RBC with the previously mentioned treatment systems. RBCs have

¹ Federal Water Pollution Control Act Amendments of 1972, Public Law 95-200 (October 18, 1972).

successfully treated the wastewaters of cities and of recreation areas not operated by the Corps of Engineers.*

Objective

The objectives of this study were to outline selection criteria for civil works personnel who must decide whether to use RBCs, provide RBC case histories for use at Corps recreational areas, and present guidance to ensure that RBC use is both economical and compatible with the Corps' needs.

Approach

These objectives were accomplished in four steps:

1. Corps district and division personnel, and pollution abatement engineers familiar with recreational area wastewaters were surveyed. Visits were made to Corps recreational areas, and to RBC sites operated and maintained by various State and National Park Service districts, and which used RBC technology.
2. The literature on RBC technology was reviewed.
3. An evaluation and economic comparison were done for RBC technology and older treatment alternatives, such as package extended aeration, lagoons, septic tanks, leaching fields, oxidation ditches, and land treatment.
4. Preliminary design guidance and a procedure for selecting RBC technology were developed for Corps recreational areas.

Outline of This Report

Chapter 2 summarizes the results of a telephone and letter survey and the findings of site visits to assess sewage treatment at Corps recreational areas, and at sites operated and maintained by various States and Park Service districts. Chapter 3 is a review of RBC literature and a documentation of existing RBC applications in recreational areas. Chapter 4 presents evaluations and economic comparisons of RBC technology and other treatment alternatives, and discusses the characteristics of RBC treatment systems for recreational areas. Chapter 5 presents a procedure for selecting RBC technology and design guidance for RBCs at Corps recreational areas.

* For more information about the operation and characteristics of RBCs, see E. D. Smith et al., Tertiary Treatment of Wastewater Using a Rotating Biological Contactor System, Technical Report N-85/ADA082502 (U.S. Army Construction Engineering Research Laboratory [CERL], February 1980); E. D. Smith et al., Upgrading DA Trickling Filter Sewage Treatment Plants, Technical Report N-102/ADA100953 (CERL, April 1981).

2 SURVEY SUMMARY AND SCENARIO DESCRIPTION

In January and February 1981, information on recreational area sewage treatment facilities was obtained in a telephone survey of 38 Corps district offices. After the survey, a questionnaire was sent to each of these offices (see the appendix). These questionnaires were returned beginning in April; 18 offices responded. In May, letters were sent as reminders to the district offices which had not replied. Table 1 shows the district offices responding to the questionnaire. The information obtained from the survey is summarized below.

Site Usage

The activities at Corps recreational areas range from camping, swimming, boating, picnicking, and fishing, to simple sightseeing from access points and overlooks, and fishing. Swimming-boating-picnicking is the major usage, followed by camping or combinations of these. At a few existing or new sites, facilities, such as equestrian areas, marinas, sailing centers, and canoe courses are planned.

All sites have sanitation facilities. An average of 36 percent of the Corps recreation areas have toilet dumping stations, but some districts reported none, and others reported that 100 percent of their recreational areas have dumping stations. The survey shows that 37 percent of the sites have shower facilities, and only 9 percent have laundry facilities. Even at camping sites, only 15 percent of the Corps recreational areas have laundry facilities.

Except in the South, most recreational areas are for seasonal activities only. However, many districts allow boating year-round, while all other activities are seasonal.

Sewage Flow Characteristics

Recreational areas usually do not measure their sewage flows. Most of the flow information obtained from this survey is designed flow rather than recorded or measured flow. Nine district offices provided some flow data (Table 2).

No detailed information is given to show the relationship between flow rates, the number of people using the sites, and the number and type of facilities. One can only assume that the flow rate given for each site is proportional to the size of the site, number of people who visit, and the type of sanitary facilities (e.g., toilet, laundry). Although information on daily flow fluctuation is not available, many district offices reported weekday average flow, weekend average daily flow, and peak or holiday flow. The fluctuations in terms of percentage of average weekday flow are given in Table 2.

The information from Table 2 confirms that sewage flow fluctuates widely at Corps recreational sites. Some facilities used seasonally have a small

Table 1
Corps District Offices

<u>District Office</u>	<u>Response</u>	<u>District Office</u>	<u>Response</u>
Alaska	X	New Orleans	
Albuquerque		New York	
Baltimore	X	Norfolk	
Buffalo		Ohio River	X
Charleston		Omaha	X
Chicago		Philadelphia	
Detroit		Pittsburgh	X
Fort Worth	X	Portland	X
Galveston	X	Rock Island	X
Huntington	X	Sacramento	
Jacksonville		San Francisco	
Kansas City		Savannah	
Little Rock	X	Seattle	X
Los Angeles		St. Louis	
Louisville		St. Paul	X
Memphis		Tulsa	X
Mobile	X	Walla Walla	
Nashville	X	Wilmington	X
New England	X	Vicksburg	

* X indicates questionnaire response received.

Table 2
Flow Fluctuations at Corps Recreational Areas
(Percent of Weekday Flow, Except as Noted)

<u>District Reporting</u>	<u>Weekend</u>	<u>Holiday</u>	<u>Offseason</u>	<u>Per Person (gpd)</u>
Fort Worth	490	--	4	--
Galveston	400	500	50	1.5
Nashville	660 to 1500	1000 to 2750	--	--
Rock Island	--	300	--	--
St. Paul	178	322	--	--
Baltimore	162	193	0-0.5	25-40
Omaha	171	214	31	--
Pittsburgh	--	990	--	5.3-23.8
Wilmington	166	250	16.7	--

flow during the offseason because a maintenance crew stays in the area throughout the year.

The range of flow rates for all recreational areas in this survey is summarized below in gallons per day:

	<u>Weekday</u>	<u>Weekend</u>	<u>Peak or Holiday</u>
Minimum:	200	1100	1700
Maximum:	20,000	45,000	60,000
Average:	12,100	23,000	30,100

The information on the average weekday and weekend flows is important. When different treatment alternatives are considered for a typical Corps district recreational area (see Chapter 4), weekday and weekend flow rates similar to those listed above will be used for design and for economic comparisons.

Sewage Influent Characteristics

This survey produced little data on sewage influent characteristics. Many Corps recreational sites monitor neither flow rate nor influent characteristics. Table 3 summarizes the data.

Table 3
Sewage Influent Characteristics

District Reporting	Biochemical Oxygen Demand (BOD) mg/L	Suspended Solids (SS), mg/L	NH ₃ -N, mg/L	P, mg/L
Baltimore	avg. 223	173 to 1440*	? to 420*	7.8 to 60*
Little Rock	200-400			
Nashville	150-200	150		
Pittsburgh	76-591 avg. 266	Total Suspended Solids (TSS) 21-873 avg. 375 Volatile Suspended Solids (VSS) 18.4-584 avg. 251		
Wilmington	25??	1.5??	0.18??	
St. Paul	280-390**	320-460**		10-15
Fort Worth	Only data given is 0.041 kg BOD/day. With a corresponding flow of 0.003468 mgd, BOD concentration is converted to 3.1 mg/L. The value is questionable.			
Rock Island	BOD data are given as an anticipated loading but no unit. It cannot be converted to concentration.			

*High concentration because the Tomkins Recreational Area uses air-assisted flushing toilets using only 4 pints water per flush.

**Uses of grinder pump can cause higher BOD and SS at times.

?Data unavailable.

??Very low values. Although not specified, it is suspected that these are values found in the aerated lagoon rather than in the influent itself.

For the limited data available, the values in Table 3 seem to agree with those reported in EM 1110-2-501.² The BOD concentration is comparable to or slightly higher than that in municipal wastewater, whereas the $\text{NH}_3\text{-N}$ concentration is higher than that in municipal wastewater, primarily because the sanitary waste in recreational areas is more concentrated.

Sewage Effluent Characteristics and Effluent Quality Standards

Since NPDES permits are required for effluents discharged into water courses, most sewage treatment facilities in Corps recreational areas monitor their effluent quality. The reported effluent quality from various Corps district offices and their corresponding State effluent quality standards are summarized in Table 4. Effluent quality is not known for subsurface discharge (leaching field, infiltration lagoon, and land treatment without effluent collection) and evaporation (lagoon), as indicated by several district offices.

The treatment systems used most often in Corps recreational areas are primarily subsurface: septic tank/leaching field or septic tank/sand filter. These are followed in popularity by the extended aeration process and lagooning. All district offices report acceptable effluent quality equal to or better than the standards required by the State. Upsets of extended aeration treatment plants are experienced by many recreational areas from time to time, resulting in BOD and suspended solids (SS) concentrations higher than the acceptable limit. This phenomenon is typical of an extended aeration process which has dispersed growth leading to poor settling in the final clarifier. Hydraulic shock loads caused by sewage flow fluctuations in a few treatment plants also could be responsible for washing out some of the biological solids. Occasional high SS concentration in the lagoon effluent is not uncommon since dispersed growth and algal cells do not settle well.

Operation and Maintenance of Treatment Facilities

The survey identified the characteristics of the operation and maintenance of sewage treatment facilities at Corps recreation areas (Table 5).*

None of the treatment facilities has a vandalism problem since all structures and treatment units aboveground are fenced and gates are locked. Electrical consumption by any one treatment facility is generally not reported because the treatment plant's power consumption is included in that of the entire recreational area (e.g., administration building, visitors' center, pumping stations, lighting). Even if a district did report the electrical consumption of a treatment plant, the data were not explicit enough to allow conversion to a kWh/mgd basis.

² Design of Small Systems Wastewater Treatment Facilities, Engineer Manual (EM) 1110-2-501, Part 2 of 3 (Department of the Army [DA], Office of the Chief of Engineers [OCE], 30 April 1980).

* In general, such information is not available for septic tank/leaching field and septic tank/sand filter systems because none of the district offices reported problems with these systems. There are almost no operation and maintenance requirements -- except for an occasional cleaning of septage for disposal.

Table 4
Effluent Characteristics in Corps Recreational Areas

Parameters	BOD, mg/L	Chemical Oxygen Demand (COD), mg/L	SS, mg/L	N, mg/L	P, mg/L	Coliform, col/100 ml	pH	Cl ₂ , mg/L
Fort Worth:								
Extended aeration	5	--	0.1	--	--	3	--	--
Req'd standard (30-day avg.)	20		20	--	--	(fecal) 200		
Galveston:								
Extended aeration	3	--	14	--	--	--	6.5	1
Req'd standards	10	--	15	--	--	--	6-9	1
Huntington	30	--	30	18 total kjeldahl nitrogen (TKN)	--	200	6-9	--
Nashville:								
Extended aeration	10-20	--	20-25	--	--	--	--	--
Req'd standards	30	--	30	--	--	200	--	--
St. Paul:								
Extended aeration	8-15	--	1-5 (turbidity, JTU* 2-3)	--	0.4	--	--	--
Req'd standards	25		30	--	1	--	--	--
Baltimore:								
Extended aeration	2-5	4	2-10	3 (NH ₃ -N)	0.3 - 0.5	--	6-7	--
Req'd standards	15-20	--	10-30	3 --	2-5	200	6-9	--
Wilmington:								
Aerated lagoon	4	92	0.05	20 (TKN)	--	--	--	--
Little Rock:								
Septic tank plus sand filters (avg. of 17 facilities)	0-34 majority 10	--	0.88 majority 20	--	--	majority 100 (Some- times 300)	6.2- 8.4	--
Extended aeration (avg. of eight facilities)	0-26 sometimes high 33	--	0.53 (4 out of 8 plants 730)	--	--	0-209	3.7- 8.1	--
Aerated lagoon (one facility)	0.4-729	--	3-8	--	--	0-110	7.2 7.7	--
Req'd standards	10-30	--	15-30	--	--	--	6-9	--
Pittsburgh								
Extended aeration (avg. of three facilities)	5.1-73 yearly avg. 22-25 (6-7 yr avg.) one facility 4 of 7 yr avg. 20 mg/L 2 of 7 yr avg. 35 mg/L		TSS 0.13-79.2 yearly avg. 22.5-42.6 (6-7 yr avg.) one facility					

* Jackson Turbidity Unit

The data indicate almost trouble-free operation and extremely low maintenance requirements for septic tank/leaching field or septic tank/subsurface sand filter systems. This history of perfect operation reported by the district offices is not consistent with the failure record of equivalent systems for household use.

There may be two reasons for this discrepancy. Inadequate size most often causes the failure of household leaching fields which were designed and built long ago when percolation tests might not have been done with proper supervision. In addition, most septic tank/leaching field systems at Corps recreational areas were conservatively designed, and thus oversized -- particularly when those systems were built before more realistic flow figures were published in EM 1110-2-501.

Table 5 indicates that lagoon systems, aerated or facultative/aerated, can be adequate for recreational area use. Sand filters installed after lagoons can eliminate high SS concentrations in the treated effluents. Very few operational problems have been reported, and sludge quantities seem to be minimal. Flow fluctuations should not hinder lagoon operation and treatment performance because of the large storage capacity for equalization. Insect problems and animal burrowing can be controlled by grass mowing and grounds maintenance; the amount of time needed for this work should not be underestimated.

Achieving good effluent quality can be a problem in extended aeration systems. Very few existing plants have sufficient equalization capacities; upsets caused by flow fluctuations have been reported by several facilities. In many plants, poor settling of dispersed growth allows solids to escape the clarifier. Compared with other treatment systems, extended aeration plants need better freeze protection to prevent operational problems and system failure in cold climates. Man-hour requirements for operation and maintenance are also relatively higher than with other treatment systems used in recreational areas because an extended aeration plant is more mechanized. Most States require at least operator level III to IV for extended aeration.

Existing extended aeration plants at Corps recreational sites generally keep their solids in the aeration system almost indefinitely -- either in the aeration tank or in the sludge holding tank under aeration. Most districts reported little or no removal of solids from the plant over several years. The St. Paul District is one exception; their plants remove solids quite often. Although a prolonged period of solid aeration can minimize solid production through endogenous respiration, the problem of disperse growth becomes worse. More significantly, energy consumption greatly increases, which compounds the problem of the high energy demand of an extended aeration process.

Cost of Treatment Plants

The first cost and operation and maintenance (O&M) costs of some treatment plants were provided by various Corps district offices. Although the cost data, as summarized in Table 6, are sketchy, it is possible to see the cost differences of the treatment alternatives. Extended aeration systems undoubtedly have the highest first costs and operation and maintenance costs, followed by lagoon systems; septic tank/leach field or septic tank/subsurface

Table 5
Sewage Treatment Plant Operation and Maintenance in
Corps Recreational Areas

Facility	Startup Problem	Sewage Load Fluctuation Problem	System Operation At Low Flow	Cold Weather Effect	Sludge Quantity	Sludge Treatment	Sludge Disposal	Winterized Or Shutdown Problem	Man-hr Requirement	Power Consumed
Fort Worth Extended aeration and lagoon with sand filter	no	---*	no	Pipe freezing, lagoon sand filter freezing, no discharge	---	Aerobic digestion	Offsite disposal (no removal in 7 yrs)	Wrap pipes in heating tapes	15/month	1.1x10 ⁶ kWh 12 plants-yr (total flow unknown)
Galveston Extended aeration	no	---	Some mechanical failure, short shutdown periods	Pipe freezing	---	---	Haul away once in 12 yrs	Pipes insulated and antifreeze in generator 7/wk	7/wk	---
Huntington Extended aeration	no	---	Mechanical problems in the rapid sand filters	Poor effluent, not meeting NPDES permit some times	---	no	Onsite land treatment or hauling	Has freeze protection sludge constantly aerated whole year	4/wk	---
Wilmington Lagoon with land applications	Yes, getting system activated	Yes, but not specified	no	no	---	no	Septic tank needs cleanup for offsite disposal periodically	no	10-15/wk sand filter & drain tile, 40/wk aerated lagoon	---
Little Rock Extended aeration	Takes time to build up sufficient biomass	Yes, but not specified	Plant upset occasionally (not specified)	Most facilities closed down	50 gal/yr	Aerated sludge lagoon	Haul away to municipal sewer	no	10/wk extended aeration, 2/wk septic tank & sand filter	---
Mobile Sand filter, extended aeration septic tank/teaching	no	no	pumps	no	---	---	Haul to landfill once/7 yrs (extended aeration)	no	10/month extended aeration	---

* --- indicates information not available.

Table 5 (Cont'd)

Facility	Startup Problem	Sewage Load Fluctuation Problem	System Failure	System Operation At Low Flow	Cold Weather Effect	Sludge Quantity	Sludge Treatment	Sludge Disposal	Winterized Or Shutdown Problem	Man-hr Requirement	Power Consumed
St. Paul	Extended aeration	Takes a few weeks to obtain a stable biological population	Yes, but not specified	---	no	no	no	Haul away once/2 wk for one plant once/month for four plants (four plants avg.)	no	40-50/wk (one plant), 20-25/wk (four plants avg.)	---
Baltimore	Extended aeration	no	Minor problem with flow transmitter	Recirculation of effluent	Freeze piping, froze on tank	3-5000 gal.	Aerobic digestion	Haul away end of season unless sludge storage capacity is exceeded	no	56/wk	105,760 kWh season 0.0037 mgd one plant
Tulsa	Lagoon or aerated lagoon with sand filters	no	no	---	no	---	no	none	no	---	---
Nashville	Extended aeration	---	no	Continuously	no	Very little, but not specified	no	Haul away once/5-6 yrs extended aeration, once/3-4 years septic tank	no	5/wk extended aeration, 2/wk sand filters	---
Seattle	Lagoon with sand filters	---	no	---	no	none	---	---	Shutdown in winter	1wk	---
Rock Island	Lagoon with sand filters	---	no	Continuously	no	---	no	none	Lagoon shutdown in winter	12-15/month, 20/month mowing, 20 hrs pre-season cleaning	---
Pittsburgh	Extended aeration	Needs 2 wks with old seed	Clarifier solids go over	Continuous but cut back air supply	None. Shutdown in offseason	---	Aerobic digestion	Haul away when needed	---	20/wk, two shifts during holiday or weekends	---

Table 6

**System Operation and Maintenance Costs of Existing
Sewage Treatment Plants in Corps Recreational
Areas**

	Treatment System	System Cost	O&M Cost
Fort Worth	Extended aeration	\$636,000/12 plants or \$53,000/plant (1974) with an average size of 16,930 gpd	\$59,000/12 plants or \$4917/plant/yr excluding replacement parts and motors and power cost
Galveston	Extended aeration	not available	\$1500/yr for average size of 8000 gpd excluding power cost
Nashville	Extended aerated	\$20,000/plant with average size of 4500 gpd \$20,000/3,000 gpd plant in 1970 \$75,000/30,000 gpd plant in 75	\$2000 - 3000/yr, power cost unknown
Waltham	Septic tank and leaching field	\$20,000/system in 1979 size unknown	not available
Rock Island	Septic tank leaching field	\$6055/plant avg. 1974-1981; size unknown	\$1000 - 2000/yr
	Lagoon	\$12,396/plant avg. 1974-1981 size 5000-10,000 gpd weekdays 10,000 to 30,000 gpd weekend peak	\$10,000 - 12,000/yr including mowing
	Trailer dump station	\$482 (1972-79)	
	Vault toilet	\$386 (1972-78)	
Baltimore	Extended aeration	\$85,000 Seven Points (weekday flow 20,000 gpd & peak 60,000 gpd) \$87,000 Rothrock (weekday flow 20,000 gpd & peak 40,000 gpd)	Two plants 3700-11,700 gpd Labor \$21,700/season Material \$8950/season Electricity \$40,000/season (projected) +\$120 fuel Seven Points 121,000 kwh/season Rothrock 157,600 kwh/season
Wilmington	Lagoon	\$20,000 each small lagoon \$307,757/600 gpd lagoon (1974)	\$5525-\$290/yr for four small lagoons \$20,000/yr for 6000 gpd lagoon Power cost \$1655-1850/yr for all four small lagoons
Little Rock	Septic tank and subsurface sand filter	\$4000-5000/unit size?	\$150/yr-unit (labor and chlorine tablets included)
Mobile	Sand filters (infiltration)		\$200/yr no power required
	Extended aeration		\$35,000/six plants of 0.046 mgd combined

sand filters are the least expensive systems. It is very difficult, however, to compare the cost-effectiveness of the various existing systems since the plants were constructed in different years; the specific effluent quality and its impact on the environment were unknown. Chapter 4 presents an analysis of the cost-effectiveness of different treatment alternatives applied to Corps recreational areas.

The survey also requested information from all Corps district offices on their planning of sewage treatment on new sites or site expansions. Table 7 summarizes the information obtained. District offices planning to add new sites and new facilities consider more favorably the treatment systems they have good experience with -- usually lagoons and septic tank/leaching systems. The districts recognize the lack of equalization capacity in existing extended aeration systems. Consequently, many offices plan on adding equalization tanks, and perhaps enlarging the final clarifier, or adding effluent filtering capabilities. These steps will help ensure a sustained high effluent quality meeting NPDES standards.

Most district offices do not plan to use RBCs in their new facilities, while a few would consider the systems if justified by cost analysis. The Baltimore District Office did such an analysis for its Mill Creek Recreational Area. The facility will have an average daily capacity of 35,000 gal. Several alternatives were considered, including extended aeration, oxidation ditch, RBC, two-stage trickling filter, and aerated lagoon. Chemical addition for phosphate removal was incorporated into each of these alternatives. The Mill Creek cost data follow:

	Construction Cost	Annual O&M Cost/Yr	Total Present Worth
Extended aeration	\$181,300	4932	340,798
Oxidation ditch	155,000	5451	335,551
RBC	214,100	5190	382,170
Trickling filter	182,000	5865	371,399
Aerated lagoon	185,000	4875	360,494

The analysis shows that oxidation ditch is the most cost-effective method. However, the cost difference between the oxidation ditch and extended aeration is very small. Since Baltimore District had more working experience with extended aeration plants, the final decision was to recommend the use of an extended aeration system.

Choosing a Treatment Technology

The survey asked Corps personnel about the information and mechanisms they used to select the wastewater treatment technology most applicable to a specific site (Table 8). The initial cost, and particularly operation and maintenance costs, are primary considerations when Corps district offices choose the wastewater treatment technology for recreational areas. Operator training and man-hour requirements are also important, as is the site specificity of the treatment system. Most district offices use EM 1110-2-501 as a

Table 7

Planning of Sites by Corps District Offices

	New Sites Planned	Expansion or Facility Planning	Technology Used in Planning	Planned to Use RBC	Reasons for or Against Use of RBC
Alaska	1	0	---	no	---
Fort Worth	0	0	---	no	---
Galveston	8	Collection system	---	no	---
Huntington	3	Add equalization tanks to plants with large flow fluctuation	Oxidation ditch & evaporation system	no	Effect of flow fluctuation
Nashville	---	---	---	no	O&M cost may be too high
Waltham	3	---	---	no	---
Portland	3	---	---	no	---
Rock Island	3	---	Stabilization ponds	no	O&M cost may be too high
Seattle	0	0	---	no	---
St. Paul	-	Add equalization tank to several facilities	Consider land application of final effluent for all systems	Would consider	---
Baltimore	0	Mill Creek Recreational Area	Extended aeration	no	Life cycle cost higher than extended aeration
Omaha	0	0	---	no	Unless site & flow require mechanical plant & if cost & energy analyses support an RBC selection
Tulsa	20	20	Lagoon	no	---
Wilmington	145	---	Primarily lagoon systems	no	---
Little Rock	0	0	---	Would consider if cost justifiable	---
Pittsburgh	1	Additional tanker for tertiary filter backwashing water & clarifier enlargement. Add equalization & sludge holding capacities	---	Would consider	---
Mobile	4	---	Septic tank with leaching fields	Would consider	---

* --- indicates no information given.

Table 8
Rationale for Treatment Technology Selection

	<u>Selection Factors</u>	<u>Information Required by Corps Personnel</u>	<u>Information Available to Corps Personnel</u>
Alaska	Initial cost, O&M cost analysis. Reliability and simplicity evaluation.	State standards, water supply based on EM 1110-2-400	EM 1110-2-501, various technical papers on Alaska experience
Fort Worth	Life-cycle cost evaluation	Visitation (seasonal) provided by planning branch	TM 5-814-3, ETL 1110-2-261 and various technical publications
Galveston	---	---	State manuals, Texas W. W. Utilities Assoc.
Huntington	Experience	Number of sites, people, sewage/person turnover rates, State requirements	EM 1110-2-501
Nashville	EPA and State approved technology most effective with fluctuation loads.	Visitation and visitation patterns, State & EPA requirements, Seasonal vs. year-round use, waste characteristics, any concentrated waste.	EM 1110-2-501
Waltham	Cost	ETLs, ETNs, Engineering Manuals	ETLs, ETNs, Engineering Manuals
Little Rock	State standards, minimal O&M and personnel requirements	State effluent standards, fixture calculations	State regulation, Ten State standards, EPA & EPA regulation and Manuals
Portland	Only considers lagoon or septic tank system because of fluctuation loads	State regulations	EM 1110-2-501
Rock Island	Initial cost, O&M cost, available trained personnel to operate, and State and local regulations	Visitation data, computation of fixture units, State requirements	ERs, ETLs, EMs, standard textbooks, State and local regulations
Seattle	Cost and site specific situations	ETL 1110-1-100 - 02 -104 -105 -101 1110-2-501 State of Washington regulations for on-site sewage disposal	

Table 8 (Cont'd)

	<u>Selection Factors</u>	<u>Information Required by Corps Personnel</u>	<u>Information Available to Corps Personnel</u>
St. Paul	Effluent limitations, land area available, water table elevation, state-of-the-art technology	Number of overnight campers, type of day use facilities provided, type of water & sewer facilities provided (hookup, etc.)	EM 1110-2-501
Baltimore	EM 1110-2-501, State design standards, NPDES permit	Number of visitors, State NPDES permit, flow records at other facilities	---
Omaha	Initial, O&M costs, site variables, State water quality standards, State requirements	Visitation, State water quality effluent standards, soil & survey data	Technical publications, textbooks, manufacturers' publications. EM 1110-2-501
Tulsa	Evaluation of performance of existing installations	State & Federal park service and health department data, & data from existing facilities	Department of Defense, Corps of Engineers, ETLs & Engineering Manuals
Wilmington	On-site soil evaluation, cost, State & county regulations, water quality standards, maintenance requirements	Visitation flow fluctuation, State requirements, no. of campsites	EM 1110-1-501 EM 1110-2-501
Pittsburgh	All technology, State & Federal requirements site specificity	Ten State standards, EPA design manuals, State permits, visitation type & facilities, prior data of existing facilities	All regulations, ETLs, ETNs, EPA Manuals & design books, & State manuals & permit requirements
Mobile	Least O&M costs	Type and number of visitation, State effluent regulations	EM 1110-2-501

guide for their system design; many offices also use U.S. Environmental Protection Agency (EPA) design manuals, State manuals, and other technical publications.

Many district offices rely on the usage records of existing recreational areas to plan the flow and size of a new treatment facility. An accurate record of the number of visitors and their activities, and data on flow and sewage characteristics related to the facilities available in a recreational area would be extremely helpful for planning. Unfortunately such records are seldom available.

States' Survey

States were surveyed for information on their recreational area sewage treatment facilities. This survey was not intended to obtain detailed information on all the States' recreational area treatment facilities. Rather the purpose was to investigate the types of treatment technology commonly used, and to assess the States' position on RBC. Only 11 States responded to this survey (Table 9). Despite the limited response, it is clear that septic tank/leaching field is used most often, followed by lagoon and extended aeration systems. Hardly any State had data on sewage flow and influent characteristics.

Generally, the States accept the use of RBC systems at recreational areas as long as specific State effluent requirements can be met. In most cases, specific requirements for an RBC facility or design criteria for the State have yet to be developed, although some general design criteria and manufacturers' manuals can be used. There are a few States which prefer simpler, less mechanized systems and therefore do not favor the RBC systems.

Federal Highway Administration Survey

A survey similar to that for the States was conducted for nine regional offices of the Federal Highway Administration (FHWA). Six of the regional offices responded but provided no information. Information gathered in telephone interviews with personnel at the Homewood, IL, and Baltimore, MD, regional offices indicates that most States use extended aeration treatment extensively at highway rest areas. FHWA does not know of any RBC facilities; however, some new techniques, such as reuse of water for toilet flushing, are being used in Virginia.

National Park Service Survey

Eleven regional offices of the National Park Service and some State departments of parks were mailed a survey similar to that for State pollution control agencies.

Table 9

State Recreational Area Wastewater Treatment Facilities

	<u>Treatment Facilities</u>	<u>Effluent Characteristics</u>	<u>State's Position on the Use of RBC</u>
Alabama	10 extended aeration, nine septic tank/ leaching fields, some lagoons, no others.	BOD, 6-24 mg/L SS 16-53 mg/L	Use of RBC acceptable if State effluent requirements are met. Has not established requirements for an RBC facility.
Arizona	100 septic tank/ leaching fields; 25-100 extended aeration, of which 3-10 have sand filters, some land treatment.	---	Same as above. Approval of RBC facility relies on general design criteria & information from manufacturers' manuals.
Connecticut	Mostly septic tank & sand filters + Cl_2 for discharge.	BOD 10 mg/L SS 20 mg/L	Acceptable if meeting the New England Interstate Water Pollution Control Commission TR-16 guides for the design of wastewater treatment works.
Kansas	70 septic tank/ leaching fields, some lagoons with sand filters (non-discharge), two extended aeration.	---	Encourages simpler but reliable systems like lagoon; RBC is mechanical system. State expects operational problem.
Maine	100 septic tank/ leaching fields, 10 lagoons with sand filters, 10 extended aeration, two land treatment.	Sand filter BOD 20 mg/L SS 20 mg/L Extended aeration BOD 40 mg/L SS 40 mg/L	Acceptable if BOD & SS both 20 mg/L can be met. Encourages lagoon system which handles seasonal flow & BOD fluctuations better.
New Hampshire	Mostly septic tank/ leaching fields, one lagoon w filter, one extended aeration + spray.	COD < 52 mg/L SS < 0.2 ? P 0.54 mg/L	Acceptable, will review RBC design criteria when submitted.

Table 9 (Cont'd)

	<u>Treatment Facilities</u>	<u>Effluent Characteristics</u>	<u>State's Position on the Use of RBC</u>
Ohio	---	---	No position taken. Use Ten States standards as a reference for plan approach.
Virginia	Mostly septic tank/leaching fields or sand filters. 10 extended aeration, some lagoons, some land application, eight trickling filters.	BOD 1.8-15 mg/l SS 2-19 mg/l	
West Virginia	---	---	State encourages septic/adsorption system, lagoons followed by settling basins, extended aeration with equalization. State has drafted general design criteria for RBC (not specifically for recreational area application).
Iowa	82 septic tank/leaching fields, 28 lagoons with filters, no others.	---	State has some reservations about RBC use because of flow fluctuations. Encourages lagoons.
Kentucky	Six septic tank/leaching fields, 25 extended aeration, 30 oxidation ditch.	---	Acceptable if State effluent requirements can be met. General design guidelines are available.

The Yosemite National Park Service indicated that in its area there are 20 septic tank/leaching field systems, two lagoon systems, two extended aeration systems, and four land treatment systems. The Arkansas Department of Parks said that the State has eight septic tank/leaching field systems, one aerated lagoon, and 20 extended aeration systems -- all performing well, with effluent BOD and SS each less than 20 mg/L.

The Kentucky Department of Parks and the Indiana Dunes National Lakeshore own RBC plants. Information on these systems is presented in Chapter 3.

Summary of Survey Results

Corps district offices favor a septic tank/adsorption system or a lagoon system for new treatment facilities; upgrading an existing extended aeration system by adding equalization capacities or sand filters is common. Even though simple, reliable, and cost-effective systems are preferred, the state-of-the-art technology such as RBC, oxidation ditch, and land treatment should also be considered at the planning stage for technology selection.

Corps Recreational Area Scenario

The data from the various surveys allow one to characterize a typical Corps recreational area. The information from this exercise will be used in Chapter 4 to analyze the costs of treatment alternatives for the typical area. Cost-effectiveness, of course, is one of the most important criteria to Corps personnel choosing among various treatment alternatives.

A typical Corps recreational area has facilities for camping, boating, swimming, and picnicking, with toilet dumping stations and showers. The area is near or adjacent to a reservoir and is for seasonal use. The sewage flow averages 12,100 gpd for weekdays, 23,000 gpd for weekends, and 30,100 gpd on holidays (peak days). The surveys provided no information on monthly distribution of flow, which is assumed to follow the pattern presented in EM 1110-2-501:

<u>Month</u>	<u>Percent of Flow</u>
April	10
May	21
June	100
July	100
August	100
September	42

When the sewage from the various facilities at the recreational area is combined, it has a BOD concentration of 250 mg/L, which is slightly stronger than municipal wastewater. Ammonia nitrogen concentration can be expected to be higher; 40 mg/L is reasonable in Corps recreational area sewage.

Effluent requirements according to NPDES permits vary from State to State. Most States require BOD and SS, 30 mg/L; coliform, 200/100 ml; and pH, 6 to 9. However, there are some exceptions -- for example, a receiving water can only accept higher effluent quality, such as BOD of 10 to 20 mg/L and SS of 10 to 20 mg/L. Effluent $\text{NH}_3\text{-N}$ and P concentrations are seldom specified in State requirements.

The typical Corps recreational area can use a septic tank/leaching field system or a septic tank/subsurface sand filter system for treatment if soil conditions allow and if approved by the State. When properly designed and installed, the system is reliable. Its first cost and operation and maintenance costs are very low. No treatment plant operator is needed. An occasional inspection of the system and periodic pumpout of the accumulated sludge from the septic tank are the only requirements. This sludge is usually hauled away for disposal once every 5 or 6 years. No effluent is discharged, so effluent quality does not have to be monitored.

The typical site may use a lagoon system when soil and groundwater conditions preclude the use of septic tank/adsorption systems, and when land is available. An aerated lagoon or facultative/aerated lagoon is preferred to save land and to avoid odor and insect problems. Sand filters are, in general, required in order to reduce the SS concentration in the effluent. The first cost and operation and maintenance costs for a lagoon are significantly more expensive than for the septic tank/adsorption system. Furthermore, effluent quality control and monitoring are required (a typical site excludes infiltration and evaporation when no effluent is charged). Lagoons are mechanically simple and easy to operate: man-hour requirements for operation and maintenance are relatively low -- an average of 30 man-hours/month. About half of this time is for mowing the grass and maintaining the grounds. Sludge production is minimal because of the prolonged endogenous respiration period. Sludge removal at the end of a season (once in several years) may be needed to minimize odor problems when the system is shut down. Lagoons handle flow and

organic load fluctuations well. Access to the treatment system area can be limited by fencing to protect the public and prevent vandalism.

When there is not enough land for lagooning, an extended aeration system is often used in a typical Corps recreational area. With highly fluctuating flow, a packaged extended aeration plant probably experiences upset occasionally. If sufficient equalization capacity is not built in the plant, a separate equalization tank is required. Even with the tank, the effluent probably contains high SS because of dispersed growth. The plant should have sand filters for polishing the effluent to assure that high effluent equality is sustained. A holding tank can store sludge so that it must be removed for disposal only once a year, or even less frequently.

Extended aeration has slightly higher initial and operational maintenance costs than lagoon systems. For operation and maintenance, 2 to 3 man-hours/day is the typical requirement. Startup of the system in the beginning of each season is slow. It generally takes 3 weeks or more to reach a stabilizing microbial population for steady performance. Because the system is relatively more mechanized, more skillful operation, maintenance, and repair are required. (Operator level III or higher should be employed.) The system is energy-intensive but is compact and occupies a small land area which can be easily fenced in.

3 LITERATURE REVIEW AND DOCUMENTATION OF EXISTING RBC PLANTS IN RECREATIONAL AREAS

This chapter: (1) reviews literature dealing with the response of RBC systems to intermittent or transient hydraulic, organic, or nutrient shock loadings; and (2) documents information about RBC systems at recreational areas. The literature is discussed chronologically.

Literature Review

1. J. A. Chittenden et al., "Rotating Biological Contactors Following Anaerobic Lagoons," Journal of the Water Pollution Control Federation (JWPCF), Vol 43 (May 1971), pp 746-754.

Although RBC technology was not applied to recreational area use in this study, its performance in receiving an anaerobic wastewater is interesting because a septic tank/RBC system is commonly available from many RBC manufacturers.

The lagoon effluent applied to the three-stage RBC system contained an average BOD concentration of 161 mg/L and dissolved oxygen of 0 mg/L. Using an overall hydraulic loading of 1.34 gpd/sq ft (hydraulic detention time = 75 minutes) and a calculated organic loading of 1.8 lb BOD/1000 sq ft-day, it took 2 weeks in startup to reach significant growth on the media. The dissolved oxygen (DO) concentration in the first stage effluent was between 0.9 to 1.5 mg/L, and a high rotational speed at 6 rpm was required to achieve this DO level. Reducing the rotational speed to 3 rpm resulted in insufficient DO or only trace amounts of DO throughout the RBC system.

The accumulated BOD removal of the three stages was 79.5 percent, 82.5 percent, and 83.2 percent, resulting in an acceptable effluent. On the first stage, there was sometimes heavy filamentous growth, which caused flow retardation. The clarifier sludge had to be removed almost every hour to prevent rising sludge. Doubling the flow, and therefore the organic loading, reduced BOD removal efficiency by 50 percent.

2. A. M. Bruce et al., "Some Developments in the Treatment of Sewage From Small Communities" (Paper presented at a meeting of the Institution of Public Health Engineers, Midland District Centre, United Kingdom, November 1972).

This study investigated the diurnal variations in flow and their effect on RBC performance. The RBC unit had 150 m² growth media. The total daily flow was 2.72 m³/day, equivalent to 1.52 kg BOD/day. To simulate a diurnal flow, a uniform flow of 1.5 Q was applied for 16 hours, followed by 8 hours without flow. The RBC performance was comparable to that of uniform flow applied throughout the day, in that the effluent BOD was about 20 mg/L (NH₃-N reduction = 33 percent). The flow pattern was changed to three peak flows, at 3 Q, lasting 2 hours; the flows were spaced 2 hours apart. This was followed by flow for 16 hours at 0.6 Q, and 8 hours without flow, as in the previous case. BOD removal efficiency was affected only slightly: effluent BOD was

raised to an average 23 mg/L, and SS was 35 mg/L, which was over the acceptable limit. A shock loading of 3.6 m³/day applied at 1.5 Q for 16 hours and followed by no flow for 8 hours resulted in poor effluent. None of the samples collected satisfied the 30 mg/L BOD and 20 mg/L SS standards.

The sludge accumulation in the RBC system was 0.6 g/g BOD applied, compared with 0.5 g/g BOD applied in an extended aeration system.

3. R. C. Wilkey et al., "Response of RBC to Shock Loadings" (Paper presented at the 5th Annual Environmental Engineering and Science Conference, University of Louisville, Kentucky, March 1975).

Using synthetic sewage (sucrose plus nutrients), the bench-top RBC startup took 7 days with acclimated seed to obtain significant growth. Using nonacclimated seed (trickling filter effluent), the startup period was 14 days.

The control experiment used 1 gpd/sq ft hydraulic flow (detention time = 2.67 hours) and the equivalent BOD load of 1.035 lb/1000 sq ft-day. The load was then raised to 2x, 4x, and 10x the control (only hydraulic load was changed, not BOD concentration). No deterioration was observed within 18 hours (short term) up to 4x the load. However, 10x the load reduced the BOD removal efficiency from 86 percent to 40 percent.

Similarly, when the hydraulic load was kept at a constant of 1.0 gpd/sq ft -- but the BOD concentration was varied to bring about 2x, 4x, and 10x the control load of 1.035 lb/1000 sq ft-day -- no deterioration was observed for the 2x load condition. However the BOD removal efficiency was dropped from 88 percent to 73 percent with the 4x load, and to 27 percent with the 10x load.

4. E. L. Stover et al., "One-Step Nitrification and Carbon Removal," Water and Sewage Works, Vol 122 (June 1975), p 66.

A small six-stage bench-top RBC unit was used to study COD removal and nitrification. No effect on COD and nitrification was detected when COD and NH₃-N loadings were raised twofold and fourfold. High COD removals remained at 85 to 90 percent for all loadings; much of the removal occurred at the first stage. Also, 82 percent NH₃-N removal was observed at the first stage. This was caused by the very low loadings used in the study; the highest shock load was 3.5 lb COD/1000 sq ft-day. The results would have been different had the authors used higher loadings for their control as well as the shock loads.

5. R. W. Corneille et al., "Treatment of Apple Waste Using RBC," Proceedings of the 30th Industrial Waste Conference (1975), p 675.

With a six-stage bench-top RBC unit and a synthetic apple waste containing approximately 900 mg/L of BOD, the authors investigated the effects of various loadings on system performance. It was found that an average of 90 percent BOD removal could be obtained at all loadings, including shock loads up to 24 times the control loading. However the highest loading test was only 0.185 lb BOD/1000 sq ft-day, which was low for RBC application.

6. F. C. Blanc et al., "Treatment of Race Track Wastewater Using RBCs," Journal of the New England Water Pollution Control Association, Vol 11, No. 2 (October 1977), p 142.

An RBC system was used to upgrade the septic tank effluent for a race track. Normally there is one 4-hour meet per day; occasionally there are two meets per day. The sewage flow during a meet averages 10,493 gal, while the flow for the entire day is 14,500 gal. The septic tank reduces the flow rate fluctuation somewhat, but the flow is not equalized. The septic tank effluent contains 456 mg/L of BOD (ranging from 250 to 600 mg/L), with 80 to 90 percent of the BOD in soluble form. Concentrations of $\text{NH}_3\text{-N}$, $\text{PO}_4\text{-P}$, and SS are 100 to 200 mg/L, 10 to 20 mg/L, and 50 to 200 mg/L, respectively.

With the RBC influent pre-aerated, and with the overall loading ranging from 0.41 to 4.17 BOD/1000 sq ft-day, soluble BOD (SBOD) removal was found to be 72 to 99 percent. The following effluent quality was observed: mean filtered BOD = 29 mg/L; maximum filtered BOD = 70 mg/L, minimum filtered BOD < 5 mg/L, and mean settled BOD = 61 mg/L. If the first stage received less than or equal to 6 lb BOD/1000 sq ft-day loading, the first stage alone removed 70 percent of the BOD. Overall BOD removal was 90 percent as long as the overall BOD loading was kept at or below 2 lb/1000 sq ft-day. Sludge production was found to be negligible when the loading was less than 0.5 lb BOD/100 sq ft-day. Beyond 1 lb BOD/1000 sq ft-day, the sludge growth was 50 percent of the applied loading. An attempt was made to maintain at least 2 mg/L of DO in the first stage. At a rotational speed of 3 rpm and pre-aeration, this DO concentration could be maintained only at a loading equal to or lower than 1.5 lb BOD/1000 sq ft-day. It was felt that the same result could be achieved by doubling the size of the first stage (removing the partition between the first and second stage) even if the overall loading were doubled to 3 lb BOD/1000 sq ft-day.

7. Metcalf & Eddy/Engineers, San Francisco Southwest Water Pollution Control Plant Project (Draft Project Report, May 1979).

A full scale (2-m diameter), four-stage RBC was tested in the San Francisco Water Pollution Control Plant. The wastewater contained 52 to 80 mg/L SBOD and 102 to 140 mg/L of total BOD. The control hydraulic loading was 1.1 gpd/sq ft. The result shows that hydraulic load forcing up to 375 percent of the control and organic load forcing up to 3 lb/1000 sq ft-day still provided a steady 82 percent SBOD removal while the effluent BOD was less than 30 mg/L. Going over the 375 percent of the control hydraulic load and/or 3 lb BOD/1000 sq ft-day, the effluent contained an average of 22 to 26 mg/L SBOD. The SBOD removal was reduced from 95 percent to 51 percent. Filamentous growth was observed on the media with organic overload condition. Use of supplemental air to the mechanical drive system prevented deterioration of process performance.

8. M. P. Filion et al., "Performance of an RBC Under Transient Loading Conditions," JWPCF, Vol 51 (July 1979), p 1925.

The study investigated the short-term response of RBC performance to transient loadings. The impulse response was significant. Recovery to new steady-state values was about 1 hour for carbon removal and 3 hours for carbon removal plus nitrification. This indicates that RBC could be sensitive to

influent fluctuations and would provide little reserve capacity to minimize fluctuations in effluent quality.

Under a steady load condition at 2 gpd/sq ft and 0.44 lb filtrable TOC/1000 sq ft-day, an effluent of steady 15 mg/L filtrable TOC was obtained. Simulated diurnal load conditions were then applied, usually 20 hours steady load followed by 10 hours of shock load, with this sequence repeated three times. When high organic loads in the diurnal variations increased up to 10 times (4.4 lb filtrable TOC/1000 sq ft-day, the effluent filtrable TOC was increased to 30 to 40 mg/L. The authors concluded that the RBC response was twice as sensitive as the activated sludge process.

9. CERL review of RBC tests, 1980.

CERL researchers, after reviewing several published reports concerning the effects of transient loads on RBC performance, made three observations.

a. In most studies, RBCs run in underloaded conditions. With such a control and steady load, an RBC can receive transient high loads, not exceeding the design load, without any adverse effects. An RBC system already loaded at or near design level will not be able to take on transient high loads without producing an inferior effluent quality. The RBC may become anaerobic if the shock load is sufficiently long or intense.

b. It is not known whether DO will become limiting in full-scale RBC operation receiving high transient loads even though the excess microbial capacity may be available.

c. RBCs were not subjected to a sustained shock load longer than 1 day in most of the shock load studies. This does not simulate conditions at recreational areas where heavy loads for 2 to 3 days on weekends or on holidays can be expected.

10. L. W. Bracewell et al., "Treatment of Phenol-Formaldehyde Resin Wastewater Using RBC," in Proceedings of the National Symposium/Workshop on RBC Technology, ed. E. D. Smith et al., Vol I (February 1980), p 733.

This study simulated a sustained shock load forced upon a two-stage, 0.5-m diameter RBC (125-sq-ft media) and monitored the response of the system. Over 10 days, the organic loading was increased from a steady loading of 21 lb COD/1000 sq ft-day, and then was increased to normal over the next 19 days. The results follow:

	<u>Steady Load</u>	<u>Shock Load</u>	<u>Effluent Concentration</u>
COD removal	63%	34%	Increased from 563 to 2007 mg/L
Phenol removal	61%	34%	Increased from 161 to 414 mg/L

When the RBC was overloaded, it was coated with Beggiatoa Spp.

11. L. W. Orwin et al., "Hydraulic and Organic Forcing of a Pilot Scale RBC Unit," in Proceedings of the 1st National Symposium/Workshop on RBC Technology, ed. E. D. Smith et al., Vol 1 (February 1980), p 119.

This report provides testing data in addition to those in the Metcalf and Eddy/Engineers study discussed above. In the San Francisco Southwest Water Pollution Control Plant, a simultaneous hydraulic and organic forcing simulated a shock load in a diurnal flow variation. The simulated shock load was brief, lasting 1 hour. The results follow:

<u>Load</u>	<u>Effluent Concentration</u>
2.1 lb TOC/1000 sq ft-day (steady load 0.5)	STOC 30 mg/L unacceptable
2.8	34
3.6	34-44
4.4	44

These results indicated that the RBC performance was sensitive to the loads, resulting temporarily in inferior effluent qualities.

12. J. C. O'Shaughnessy et al., "Nitrification of Municipal Wastewater Using RBC," in Proceedings of the 1st National Symposium/Workshop on RBC Technology, ed. E. D. Smith et al., Vol 2 (February 1980), p 1193.

Under a steady load of 0.2 lb NH₃-N removal, this bench-scale study showed that doubling the flow rate (3 hours per stage reduced to 1.5 hours per stage) increased the effluent NH₃-N concentration of a single-stage unit, but no deterioration of performance for a four-stage unit was detected. Sudden increase of ammonia loading rate, however, did increase the NH₃-N in the effluent of the four-stage unit.

13. R. Viraraghavan et al., "Design and Operation of Two RBC Plants at Fundy National Park, New Brunswick, Canada," in Proceedings of the 1st National Symposium/Workshop on RBC Technology, ed. E. D. Smith et al., Vol 2 (February 1980), p 1137.

The performance of RBCs in upgrading septic tank effluents at two campgrounds was studied during the summer of 1979. Preliminary results are reported. The septic tanks removed about 30 percent of the BOD in raw wastewater, leaving 100 to 120 mg/L in the effluent. Flow rate was not measured.

The RBC performance at the Headquarters' plant was:

	<u>BOD</u>	<u>SS</u>	<u>% BOD removal</u>	<u>% SS removal</u>
Influent	160	47	--	--
RBC effluent	48	35	70	--
Clarified effluent	30	15	82	68

The RBC performance at the Point Wolfe Plant was:

	<u>BOD</u>	<u>SS</u>	<u>% BOD removal</u>	<u>% SS removal</u>
Influent	50	22	--	--
RBC effluent	32	33	--	--
Clarified effluent	10	9	80	59

Existing RBC Plants in Recreational Areas

Information was requested from operators of 29 RBC plants at recreation areas in the United States and Canada. Only eight plants provided information; this is presented below. (Two others responded but provided no data.)

Camp Horseshoe RBC Sewage Plant, Tucker County, WV

Camp Horseshoe has the oldest existing RBC plant of the recreational areas examined for this study. In addition to the information provided by the West Virginia Department of Health and by the YMCA Camp Horseshoe Director, data on treatment performance from an EPA study of the plant is used here.³

Camp Horseshoe has been a summer camp with an enrollment of about 1500 persons over 12 weeks. There is, however, a plan to winterize it for year-round operation. The RBC plant was installed in 1971 (Figure 1). It is a package treatment plant with a design capacity of 8900 gpd. Plant specifications are presented in Table 10.

Waste enters the ground by gravity into an underground rectangular septic tank. The clarified waste then overflows into the buffer tank from which it is raised to the RBC unit above the septic tank by two 0.152 m³/min (40 gpm) float-controlled pumps. An overflow line is provided to permit flows in excess of design flow to return from the feed tank to the buffer tank. Four bucket feeders attached to the main shaft collect the waste from the feed tank and take it to the first stage of the RBC. Waste flows from stage to stage through openings in the bulkheads, and then into a final clarifier. Clarified effluent can be recycled from the final clarifier to the septic tank through a valved gravity overflow line. Sludge which has settled out is removed by a rotating scraper with hollow connecting arms, through which the sludge flows by gravity to the septic tank. Effluent normally passes from the final

³ W. A. Sacks, Evaluation of the Bio-Disc Treatment Process for Summer Camp Application, EPA-67012-73-022 (U.S. Environmental Protection Agency [EPA], August 1973).

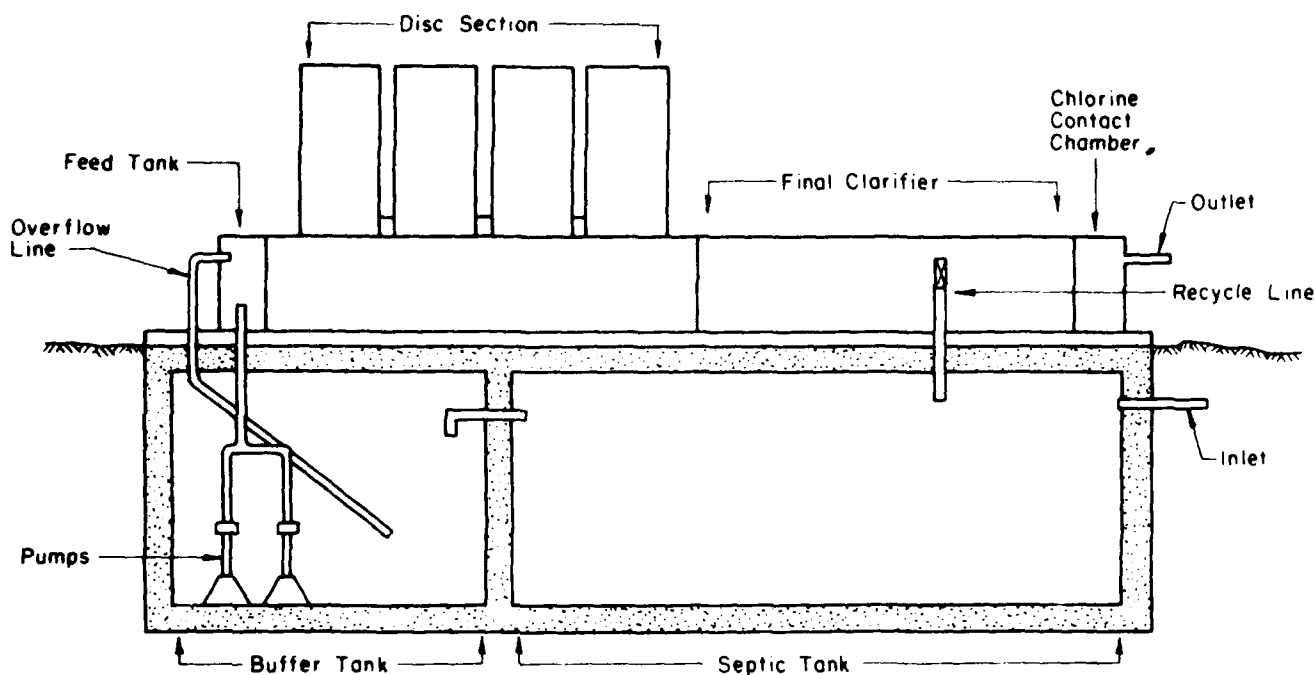


Figure 1. Schematic diagram of Camp Horseshoe bio-disc plant.

clarifier to a chlorine contact chamber for disinfection, and then is discharged from the plant to an area of land (about 1 acre) planted with pine trees that are about 30- to 40-ft tall. The irrigation plumbing is above grade and is sloped to drain between dosings. There is no freezing problem since the camp is closed early in September.

The entire aboveground portion of the plant is enclosed by a garage-like structure with an exterior which matches the other buildings in the camp. The structure provides weather protection for the unit and its associated controls, and helps maintain the aesthetic appearance of the area.

The facility is truly a "package plant." All unit operations are performed by the septic tank, buffer tank, and the bio-disc unit itself. While the bio-disc section offers secondary biological treatment and final clarification, the septic and buffer tanks provide primary sedimentation, concentration, and digestion of raw biological sludge, solids, storage, flow equalization, and mixture and seeding of the raw waste with the recycled bio-disc sludge.

The sewers at the camp serve two toilet and shower buildings, the camp kitchen, and the camp infirmary. In addition, three outdoor privies reduce the waste load on the plant. The sewer line from the camp area to the plant is 1200 ft. This relatively short run prevents significant breakup of the sewage solids flowing to the plant. There is no dumping of chemical toilets into the system. The EPA study showed that the average flow on weekdays was 4455 gpd. The camp generally was not used on weekends. The daily flow during

Table 10
Plant Specifications

1. Septic tank volume.....	8900 gal
2. Buffer tank volume.....	3700 gal
3. Feed tank volume.....	160 gal
4. Disc section volume, gross.....	1300 gal
5. Disc section volume, net*.....	570 gal
6. Submerged volume of discs.....	730 gal
7. Total effective disc area.....	5800 sq ft
8. Final clarifier volume.....	1220 gal
9. Final clarifier surface area.....	58 sq ft
10. Disc velocity.....	2 rpm
11. Disc diameter.....	6.5 ft
12. Number of stages.....	4.000
13. Number of discs per stage.....	22

*As measured with no biomass growth.

the entire week (including the weekend) was only 3860 gpd; the peak daily flow was 6320 gpd. All these rates were considerably lower than 8900 gpd, the design flow. According to records as of April 1981, the camp never has over 200 people at the same time. Using a per capita flow of 31 gpcd (range from 25 to 39 gpcd), the flow of the camp has never exceeded the design flow.

The short line from the camp area to the RBC plant allows little infiltration. In the EPA study, the sewage was found to be stronger than normal because of the insignificant dilution. During the seasonal startup period in 1972, the RBC unit was pre-seeded with sewage and sludge from the septic tank. Continuous recirculation of the sewage was applied for 2 weeks, after which a stable BOD removal at 80 percent was achieved.

During the last 5 weeks of the 10-week EPA evaluation period, the average BOD removal for the RBC system was 85 percent. The average flow, however, was only 3860 gpd. The hydraulic detention time was 7.6 hours instead of the design 3.5 hours, and the resulting clarifier overflow rate was 66.5 gpd/sq

ft. The calculated hydraulic and organic loads were 0.1 to 1.0 gpd/sq ft and 1.35 lb/1000 sq ft-day, respectively.

Nitrogen removal was not significant in the EPA study. There were removals of TKN-N of 37.5 percent and $\text{NH}_3\text{-N}$ of 25.2 percent. Effluent samples also showed 4.0 mg/L of nitrite and 5.7 mg/L of nitrate. No phosphorus removal was detected, and 90.5 percent total coliform reduction (including the septic tank) was reported.

Sludge accumulation in the septic tank has been insignificant. Septage, removed only once since 1972, was taken to a landfill or a nearby municipal sewage treatment plant. It has been estimated that 5000 gal of septage, or fewer, need to be removed from the septic tank once every 5 years.

The RBC plant does not have a separate meter to record electrical consumption. The power requirement for operation is not known, although it has been estimated at \$400 to \$600 a year for seasonal operation. A U.S. Forest Service employee spends about 2 hours a day with the system. Part of that time is spent on tests and reports required by the Forest Service. No effluent is collected for quality monitoring. However, the Forest Service tests a nearby stream every week to ensure that it is not being polluted by the system.

The RBC plant has not had any failure or operational problems. The only difficulty so far has been caused by malfunctioning electrode switches which activate the sewage pumps. These switches were replaced once because of a corrosion problem; there is a plan to replace them with mercury float switches to solve the problem permanently. An engineer from the West Virginia Department of Health who inspected this RBC plant on April 28, 1981, was impressed with the condition of the facility, which is now 10 years old.

*Boldt Castle RBC Wastewater Treatment Facility,
Heart Island, NY*

Another early RBC installation is at Boldt Castle, an old castle now primarily a sightseeing attraction. The RBC system was installed in 1972.

The treatment process at Boldt Castle is the bio-disc system. This consists of a primary settling tank (septic tank), which is also used for secondary sludge digestion; a holding tank or wet well, which is used for flow equalization; the bio-disc unit; a sludge return pump and chamber; a chlorine contact chamber; and an outfall line to the river.

The bio-disc unit consists of several large discs (about 10 ft in diameter) which are mounted on a horizontal shaft and placed in a semicircular tank. The discs are rotated while approximately one half of their surface area is submerged in the wastewater; a film of biological growth forms on the rotating discs. As the shaft turns, alternately exposing the discs to the wastewater and to the air, the growth contacts organic impurities and the wastewater is aerated.

A slowly rotating bucket mechanism scoops the solids from the settling tank in the bio-disc unit; they flow by gravity to the sludge pump chamber, which pumps the solids to the primary settling tank for digestion and storage.

The effluent from the system flows into a chlorine contact chamber where it is mixed with chlorine and detained for disinfection before being discharged into the river. Chlorination is seasonal, coinciding with resort operation. Up to 100 percent circulation is used during extremely low flows, resulting in no discharge. Emergency power is not provided. Figure 2 is a detailed schematic of the treatment process.

This system began operating in the summer of 1973. No tests of plant performance were done in the first season of operation. Flows in 1974 were so

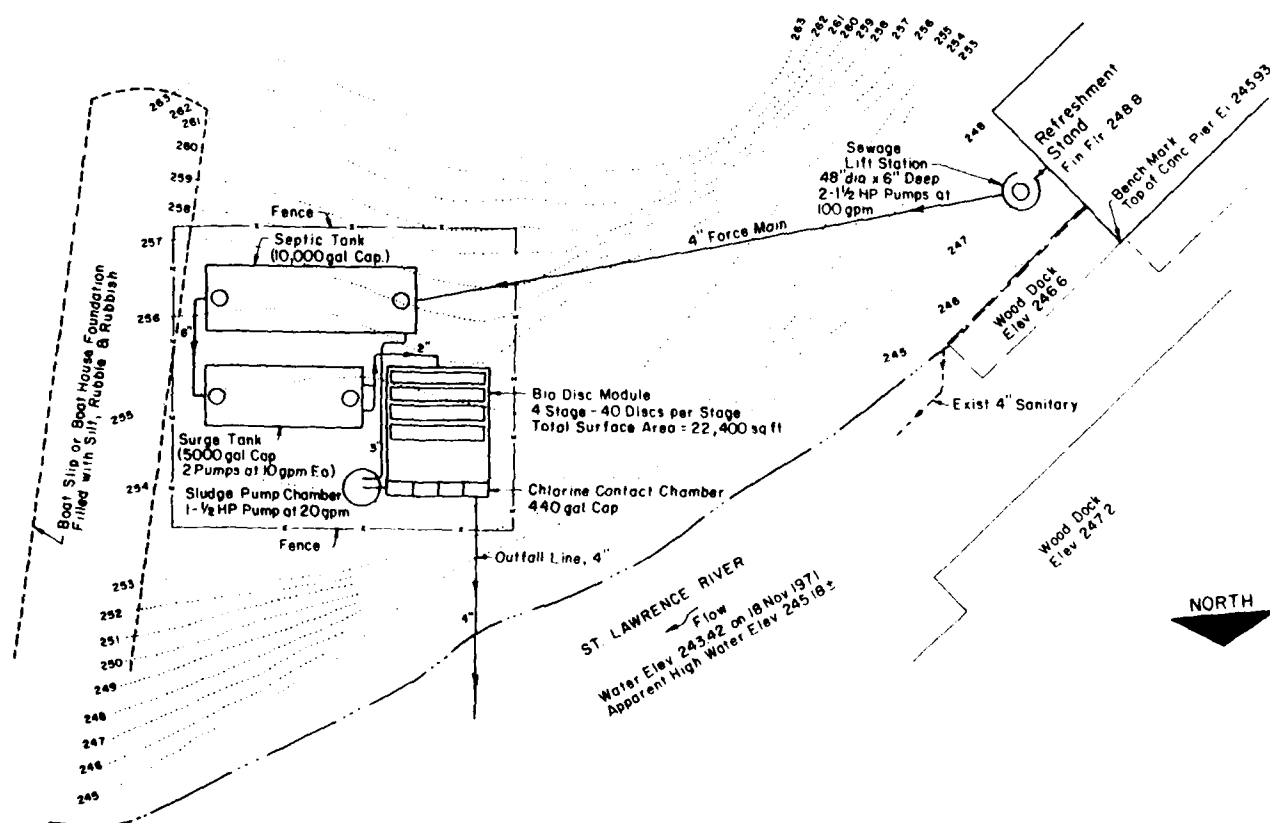


Figure 2. Boldt Castle treatment process.

low that 100 percent recirculation of treated effluent resulted in zero discharge to the receiving stream until after the tourist season, at which time all of the treated effluent was discharged to the river. Since flow metering is done at the discharge end of the plant, no records exist for minimum, average, or maximum daily flows. Design values are given in Table 11.

Table 12 is a detailed plant description. Table 13 gives the results of the only tests performed to date; the effluent sample was taken July 17, 1974.

The effluent BOD at 40 mg/L could be misleading. Since both nitrite and nitrate levels indicate a highly nitrified effluent, the 5-day BOD test of the effluent very likely includes a significant portion nitrogenous oxygen demand (NOD). In other words, the effluent carbonaceous BOD value could be much lower than the reported 40 mg/L value had it been corrected for the NOD value.

No sewage flow was measured; however, a water meter shows 2000 gpd of potable water flow for the past several seasons. It appears that the sewage flow is not coming close to the anticipated average of 9000 gpd and the maximum of 15,000 gpd. Sludge has never been removed -- not enough has built up since the plant started in 1973.

The plant has a fiberglass cover over the RBC unit, and the aboveground portion of the whole plant is fenced for vandalism protection. During the tourist season (May 15 to October 15), 1 man-hour/day is required for operation and maintenance. Starting the system in the spring and shutting it down in the fall takes two people about 2 days. Major cleanup and maintenance -- cleaning the plant, close inspection for wear, adjustments, minor painting -- may be needed once in 7 or 8 years. This work takes two people about 5 days.

The Thousand Islands Bridge Authority reports that before it assumed ownership, the RBC plant was poorly maintained. Minor chain and motor problems have developed, but most of these were caused by prior neglect of adjustments.

Table 11

Design Values for Boldt Castle RBC System

Flow gpd based on 5 gpcd:

Minimum = 150
Average = 9000
Maximum = 15,000

5-day BOD: 200 mg/L

Total suspended solids: 150 mg/L

Temperature: 55 to 60°F

Average design population: 1800

Table 12

Boldt Castle Wastewater Treatment Facility's
Basis of Design

1. Type of treatment:
Primary settling tank (septic tank); followed by the bio-disc secondary treatment process
2. Maximum design population:
3000 people
3. Maximum sewage flows:
15,000 gpd
4. Classification of St. Lawrence River at Heart Island: "A"
5. Sewage lift station:
48-in. diameter x 6-ft deep
Two pumps at 100 gpm each, 25-ft head, 1-1/2 hp
6. Primary settling tank:
10,000 gal, 12-ft wide x 32-ft long x 11-ft high
7. Holding surge tank with pumps:
5000 gal, 12-ft wide x 16-ft long x 11-ft high
Two pumps at 10 gpm each, 25-ft head, 1/2 hp
8. Bio-disc treatment unit:
Four stages, 40 discs each stage
Total surface area = 22,400 sq ft
9. Sludge return pump and chamber:
48-in. diameter x 3-ft deep
1-1/2 hp, 20 gpm, 15-ft head
10. Chlorine contact chamber with hypo-chlorinator:
Capacity: 440 gal
Detention: 42 minutes

Table 13
Results of Composite Sample

<u>Parameter</u>	<u>Final Effluent</u>
BOD (5-day), mg/L.....	40
COD, mg/L.....	120
Settleable solids mg/L.....	0.1
Total solids, mg/L.....	484
Volatile solids, mg/L.....	84
Total suspended solids, mg/L.....	20
Volatile suspended solids, mg/L.....	18
pH.....	5.7
Chloride, mg/L.....	120
Total phosphate, mg/L.....	11.3
Alkalinity, mg/L.....	43
Free ammonia, mg/L.....	19.5
Organic nitrogen, mg/L.....	30.8
Nitrite, mg/L.....	8600
Nitrate, mg/L.....	110
Turbidity (JTU).....	4

The plant has performed without failure for 8 years. There is a plan to rebuild four scoops and the skimmer with stainless steel. The New York permit of discharge for this plant is listed below. All standards have been met.

BOD:	30-day average	30 mg/L
	7-day average	45 mg/L
	or 85 percent removal	

SS:	30-day average	30 mg/L
	7-day average	45 mg/L
	or 85 percent removal	

pH: 6 to 9

Fecal coliform not greater than 200 MPN (most probable number)/
100 ml for a period of 30 consecutive days.

*Albert Lea Information Center Biomodule RBC Sewage Treatment,
Albert Lea, MN*

This treatment facility is used year-round and has operated since 1975. Owned by the Minnesota Department of Transportation (DOT), the plant was installed in 1974. It consists of a septic tank, a buffer tank, an RBC unit 2 m in diameter with four-stages, a clarifier chlorination tank, and a holding pond (Figure 3). This package plant operates like the one at the Camp Horseshoe YMCA facility.

While the size of each treatment unit was not given by the Minnesota DOT, the plant capacity, as originally installed, is 80,000 gpd with four feed buckets in operation. The plant is actually treating about 2740 gpd. Because of this very low influent volume, the bucket feed rate was reduced to 200,000 gpd in 1980.

The direct discharge standards in Minnesota for this type of installation are as follows:

BOD ₅	25 mg/L
TSS	30 mg/L
Turbidity	30 JTU
Fecal coliform	200 MPN/100 ml
pH	6.5 to 8.5

The wastewater and effluent characteristics furnished by the Minnesota DOT are given in Table 14.

The discharge parameters, as the data show, have been consistently met. However, because of evaporation and seepage, this pond has never been discharged. (Minnesota standards for pond seepage are less than 500 gal/acre/day.)

The RBC unit is in a locked wood-frame building, and is therefore protected from vandalism and the weather. The capital cost for the treatment facility -- which includes the RBC, septic tank, buffer tank, control system, and the wood superstructure -- was \$44,000 in 1974.

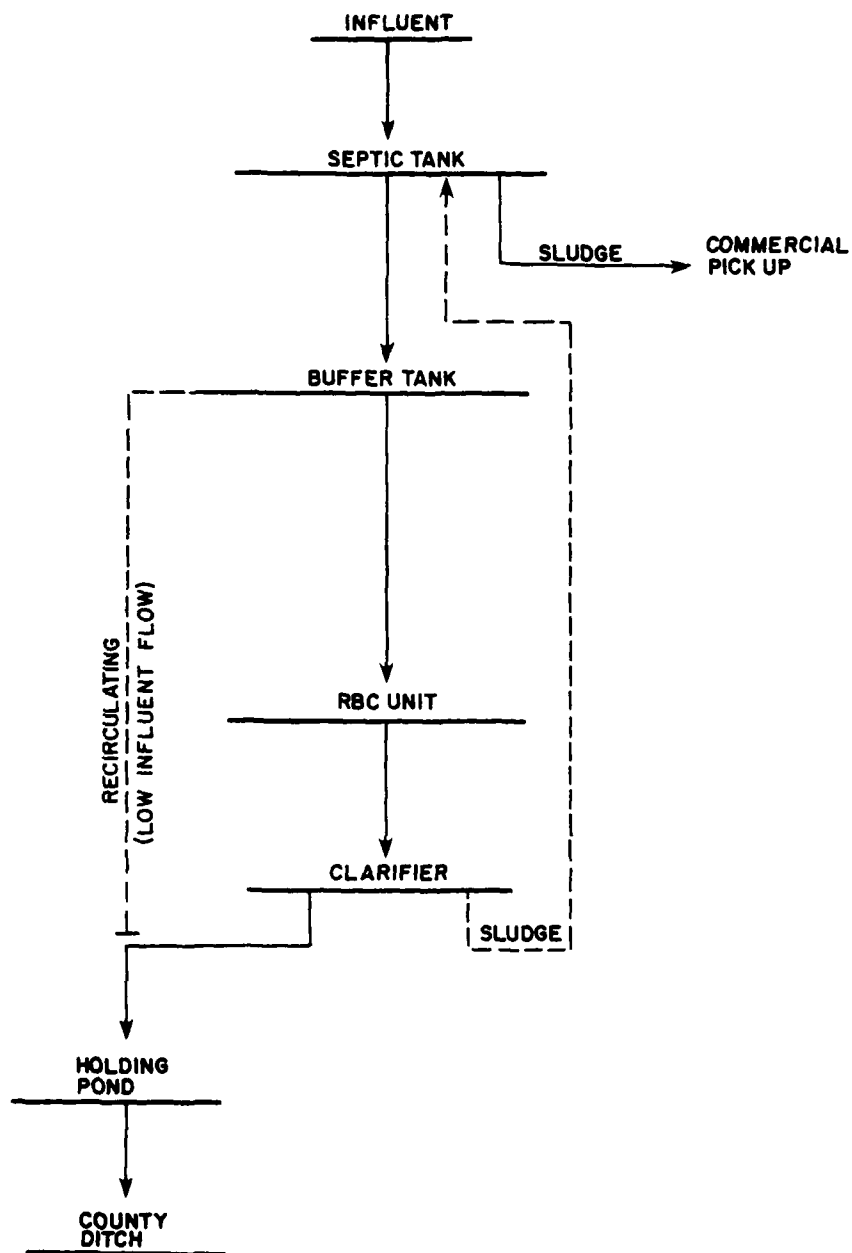


Figure 3. Albert Lea Information Center RBC.

Table 14
 Boldt Castle Wastewater and Effluent Characteristics
 (in mg/L)

Raw Wastewater (no chemical toilet dumping)						
	BOD ₅	SS	NH ₃ -N	TKN	DO	Total-P
Average	187	138	20.7	88.3		10.2
Range	44-300	26-800	7-81	16.8-130		8.6-11.8
RBC Influent or Septic Tank Effluent						
Average	30.2	22.9	8.5	16.2	4.2	8.7
Range	2-105	5-63	0.95-41	2-46	0.8-9.6	7.2-10.5
RBC Effluent						
Average	28	19.5	7.5	13.5	11.1	9.1
Range	1-94	3-44	0.6-38	1.1-43	4.0-27	0.8-15.6

The septic tank has a storage capacity large enough that sludge has not been removed from the treatment facility since 1975. Operation and maintenance of the plant normally takes about 8 man-hours/month. The RBC biomodule has never failed. However, the tapered roller bearings did have to be replaced once.

*Indiana Dunes National Lakeshore RBC Sewage Treatment Plant,
 Porter, IN*

The Indiana Dunes National Lakeshore National Park has 16 septic tank/leaching field systems, in addition to one lagoon/sand filter system and one land treatment system. In 1976, a new treatment system was installed consisting of a septic tank, a surge tank, an RBC unit, a clarifier, a chlorination tank, and a leaching field. This system is not complicated; the chlorination tank, for example, is in Figure 4. Figure 5 shows the RBC. Note that location and landscaping have made the site as inconspicuous as possible to park visitors.

The system operates year-round with an average weekly flow of 1000 to 2000 gpd, weekend flow of 2000 to 5000 gpd, and peak flow of 3000 to 6000 gpd. The septic tank has a capacity of 1400 gal. The wastewater overflows from there to a 400 gal surge tank from which two float-operated submersible pumps raise the wastewater to the RBC unit. The RBC unit is a three-stage; 11-ft, 3-in. diameter; 10-ft shaft (33,000-sq ft media) EPCO Hormel system in concrete tankage. The clarifier has a chain belt sludge collection mechanism which uses an air-lift pump to return the settled sludge to the septic tank. The chlorinator and pump controls are in a small cinder block structure on top



Figure 4. Chlorination tank at Indiana Dunes National Lakeshore.

of the septic tank and the sewage tank; the RBC unit has a fiberglass cover. The aboveground structures are surrounded by fences with locked gates.

The RBC influent contains 25 to 70 mg/L of BOD and 20 to 40 mg/L of SS. The average RBC effluent quality is 15 to 25 mg/L of BOD and 5 to 19 mg/L of SS. Since there is no surface discharge, no State discharge permit is required. The treatment and chlorination provide a high quality effluent to protect the groundwater resources in the area.

Despite the small size of the septic tank and the buffer tank, which do not provide much equalization capacity to the daily fluctuation flows, the plant seems to work well. Calculations using even the peak flow and peak BOD concentration show that the maximum hydraulic flow is only 0.18 gpd/sq ft, and the organic load is 0.106 lb BOD/1000 sq ft-day. The RBC unit is significantly underloaded and should perform well even if no equalization capacity is provided in the system. The equipment cost \$45,000 in 1975, while the cost of the complete system was \$110,100 under Government contract and customized installation.

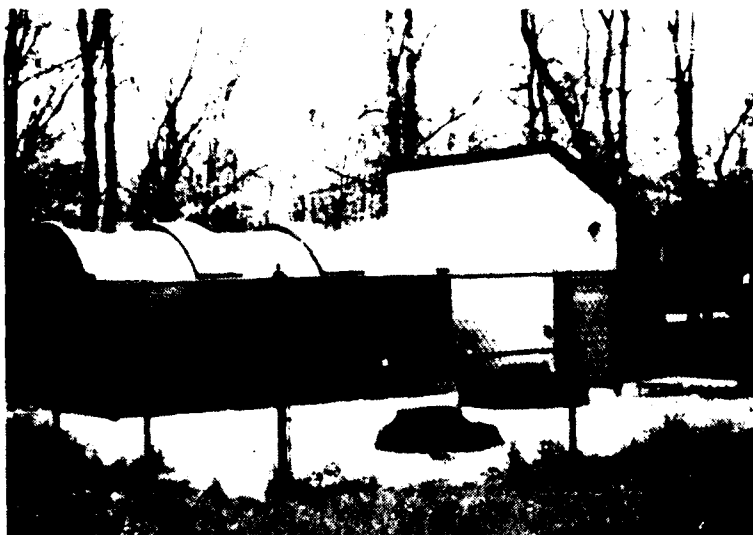


Figure 5. The RBC at Indiana Dunes National Lakeshore.

The system has not failed since it was installed. However, some mechanical changes were made by Park Service personnel. The original positive displacement screw-type sewage pumps in the surge tank were not working properly, and were later replaced with two submersible centrifugal pumps. Also, the original positive displacement diaphragm pump for sludge did not work well and was replaced with an air-lift pump. The screw-type pumps were frozen during a period of extremely cold weather (six consecutive days of sub-zero temperature). A heater now warms the control room and the RBC unit if necessary, but has not been used since installed.

The treatment facility takes only 16 man-hours/month for operation and normal maintenance. Sludge is pumped out once a year from the septic tank for off-site disposal. The small septic tank capacity does not allow a significant build-up of sludge. Because the treatment facility is metered with other buildings nearby, power consumption for the treatment operation is not known.

*Kentucky Horse Park Wastewater Treatment Plant,
Fayette County, KY*

The Kentucky Horse Park Wastewater Treatment Plant is an advanced wastewater treatment facility providing better than secondary treatment. The plant also accommodates wastewater from the University of Kentucky Spindletop complex that is southeast of the Horse Park. The flow from Spindletop complex is

estimated to be 27,000 gpd. The combined design flows coming into the plant are:

Peak summer day: 150,000 gpd
Average summer day: 90,000 gpd
Average winter day: 50,000 gpd

The other design criteria are:

BOD: 85 percent removal or 20 mg/L effluent BOD
SS: 85 percent removal or 25 mg/L effluent SS
Nitrification: 85 percent removal or 3 mg/L effluent $\text{NH}_3\text{-N}$
Fecal Coliform: 200/100 mg/L monthly average; 400/100 ml weekly average
pH: 6 to 9

Figure 6 is a flow diagram for the treatment plant. Plant unit capacities and criteria are given in Table 15.

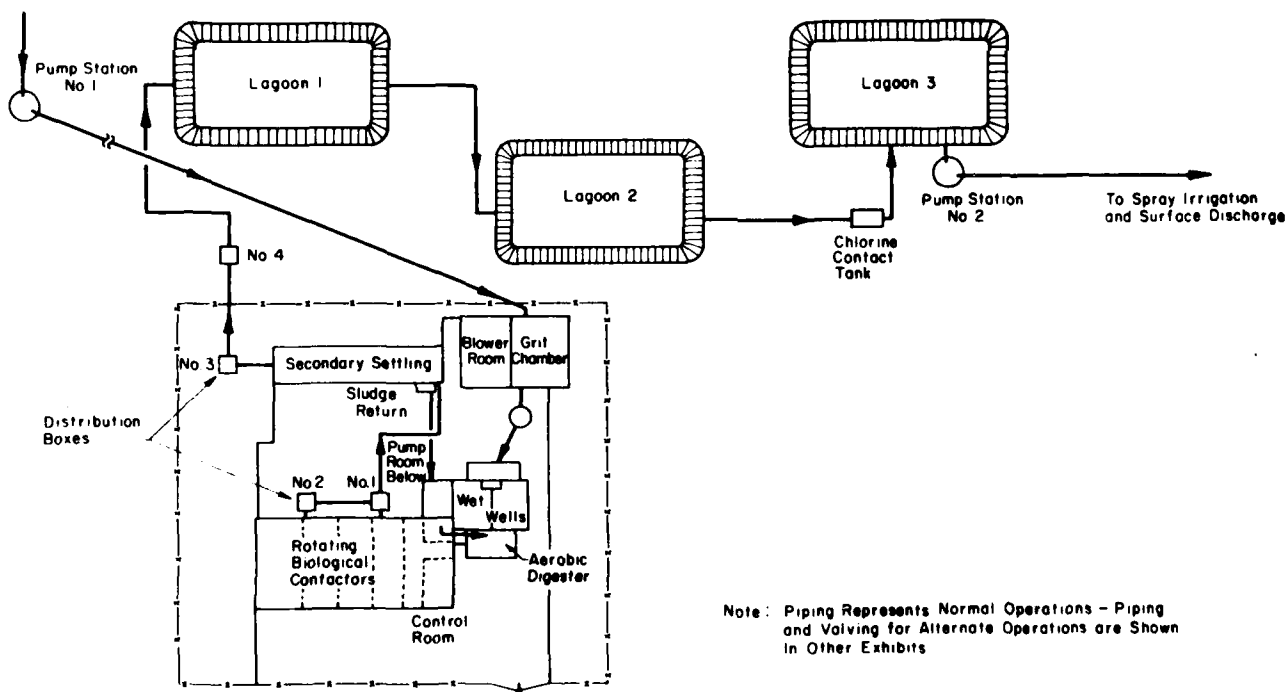


Figure 6. Kentucky Horse Park Wastewater Treatment Plant.

All raw wastewater from the park and Spindletop is pumped to the treatment plant by pumping station No. 1. A magnetic flow meter measures the flow and records it on a 7-day chart. The wastewater then goes into a chamber which is a two-channel structure -- one channel housing the comminutor and the other accommodating 2-in. x 1/4-in. aluminum bars with 1-in. clear openings. A grit removal channel follows. After leaving the grit chamber, the flow is piped to one or both of two raw sewage wells. The wet wells provide some (but not significant) equalization of the flow to all of the treatment units that follow.

Table 15

Plant Unit Capacities and Criteria

Comminutor	Capacity, 30,000 to 450,000 gpd
Grit channels (2)	Capacity, one channel -- 150,000 gpd @ 400 gpm
Raw sewage wet well #1	Volume, 18,900 gal
Raw sewage wet well #2	Volume, 18,900 gal
Stationary screen	Capacity, 400 gpm
Aerobic digester	Volume, 19,500 Air supply, 200 cfm @ 6 psig
RBC(2)	Designed for BOD -- 300 mg/L, N -- 35 mg/L Two shafts, four stages each Media area, 176,000 sq ft per shaft
Secondary settling tank	Volume, 40,500 Detention time, 130 mins @ 150,000 gpd
Surface settling rate	1000 gpd/sq ft @ 150,000 gpd
Lagoons (3)	Each lagoon: Surface, 10,000 sq ft Volume, 375,000 gal Detention time, any two units provide 5 days @ 150,000 gpd Depth, 5 ft
Chlorinators (2), tablet-feed	Each unit: Capacity 50,000 gpd* Cl ₂ residual up to 2.0 mg/L
Chlorine contact basin	Volume, 9720 gal Detention time, 31 mins @ 150,000 gpd

*When the raw sewage flow reaches an average of 100,000 gpd, a gas chlorinator will be required.

From the wet wells, the sewage is pumped to a stationary screen where larger solids are removed. The screenings fall into a solid channel which flows by gravity to an aerobic digester. There is a small spray unit at the head of the channel to help flush the solids into the digester. The liquid portion after the stationary screen goes to the RBC unit. Sludge from the RBC is discharged by a travelling siphon mechanism to the aerobic sludge digester. The RBC effluent moves by gravity flow to a series of lagoons. The effluent usually goes into lagoon No. 1, then No. 2, and then to No. 3. Several methods of piping may be used to bypass any one of the lagoons.

All lagoons are concrete lined. The first two are a tertiary treatment unit. The third is a holding tank to provide equalized flow to a spray irrigation system. This last lagoon receives the effluent from lagoons No. 1 and 2 after it passes through the chlorine contact tank. After spray irrigation, the effluent is discharged to a surface stream. Pumping station No. 2 is used to pump the effluent from lagoon No. 3 to the spray irrigators periodically. The irrigation system is set up so that each lateral will be operated on a time sequence. As one lateral shuts off, the next in sequence will activate. This continues until the circuit is completed or the pumps deactivate.

In the RBC plant there is a pump room consisting of 45 plug valves, two sludge pumps, three raw sewage pumps, one plunger pump, a water seal unit, and a sump pump. The pump room has been designed so that any two pumps can operate the entire secondary process. This gives the operator a flexibility that is not usually found -- even in the larger sewage treatment plants.

This plant, for its flow and effluent requirements, is very sophisticated. All process piping is interconnected and valved so that it may be used several ways. Any centrifugal pump in the plant may be used, as required, for any pumping purpose. Any basin, tank, or unit process may be bypassed to any other unit. Raw sewage can bypass the process treatment units entirely, but must, at a minimum, pass through a lagoon and chlorination before discharge. Pumping station No. 2, which handles final effluent to the spray irrigation system and the surface discharge point, can return its entire discharge to the treatment plant ahead of the stationary screen for recirculation through the plant.

The installation cost of the plant in 1977 was \$1,300,000, according to the Kentucky Department of Parks. This RBC plant normally operates with two shifts of personnel, but with only one in winter. Because of the sophistication of the plant operation, the chief operator has to be a Kentucky class 4 operator; he/she is assisted by two or three full-time class 1 operators during the tourist season. The operation and maintenance cost is about \$45,000/year.

The entire RBC, the stationary screen, the control panel, and a small laboratory are in a building with proper mechanical ventilation. The plant has performed very well; there have been no equipment breakdowns. Maintenance of the RBC unit is strictly according to the manufacturer's recommended schedule. In this plant, sludge has to be cleaned from the aerobic digester and hauled to nearby landfills.

It may be difficult to justify the sophistication and the costs of this plant for its flow and for its application to recreational area use. Minimal

operation and maintenance costs are important when treatment alternatives are being compared. Note, however, that the high installation and operation and maintenance costs of this facility are not for the RBC unit alone, but for other equipment which adds significantly to the expense.

*Gros Morne National Campground RBC Sewage Treatment Plant,
Rocky Harbor, Newfoundland*

Gros Morne National Campground has 150 sites, each averaging three persons per night during the camping season. The facility is used for about 6 months -- May to October.

The sewage flow is not known. It goes into a septic equalization tank 10 ft x 25 ft x 10.75-ft high from which it flows by gravity to a four-stage, 3.2-m diameter, 15-ft shaft RBC unit with a bucket feed mechanism. The RBC effluent drains into a cone-shaped Chicago Pump Model SL-131 clarifier. From there, the effluent flows by gravity to a chlorination tank equipped with a Sanuril Model 1000 Chlorinator. The settled sludge is returned to the septic-equalization tank by a Moyno Pump No. 214. The entire RBC unit, the clarifier, and the chlorination tank are housed for protection from the weather. There is no heating in the plant.

The RBC unit has not failed in the 4 years since it was installed. For operation and maintenance, about 60 man-hours per month are required. Operation and maintenance costs are estimated to be \$500/year. No sewage influent and effluent data are available.

*Alaska Lumber and Pump Logging Camp RBC Sewage Treatment Plant,
Juneau, AK*

The population at the Alaska Lumber and Pump Logging Camp varies from 50 to 125. The sewage flow fluctuates widely because everyone works the same hours; the peak flow occurs for a 2-hour period during the day.

The sewage flow comes into a 15,000 gal, two-compartment steel septic tank with baffles and bypass piping. The tank, significantly oversized, is sealed and has an elevated vent to equalize the flow. This septic tank is outside and aboveground; it has exposed piping insulated with polyurethane foam insulation. From the wet-well compartment of the septic tank, the sewage is raised to the RBC unit by float operated pumps.

The RBC is a four-stage, bucket-feed unit with a maximum design capacity of 43,000 gpd (30 gpm). The packaged unit with clarification and chlorination is enclosed in a heated building. There is a bypass line from the septic tank, allowing the effluent to discharge without going through the RBC unit. This is permitted in winter, when the population is as low as 12 to 15. The RBC sludge is returned to the septic tank.

There is a plan to pump and clean the septic tank once a year, and to deposit the sludge in an excavation along one of the many logging roads in remote areas. The U.S. Forest Service and Alaska Department of Environmental Conservation officials have indicated that this practice would be acceptable, although permits have not been secured.

The RBC treatment plant was installed in October 1980. Only one effluent sample was obtained, showing 5.0 mg/L SS and 45 mg/L BOD. The peak power requirement, including electric heating, is about 5 kW. Operation and maintenance is estimated to take 20 man-hours/month, excluding the annual septic tank pump-out. (These observations are based on the very limited operation of this plant thus far.)

*Bolar Mountain Recreational Area RBC Sewage Treatment Plant,
Lake Moocaw, Bath County, VA*

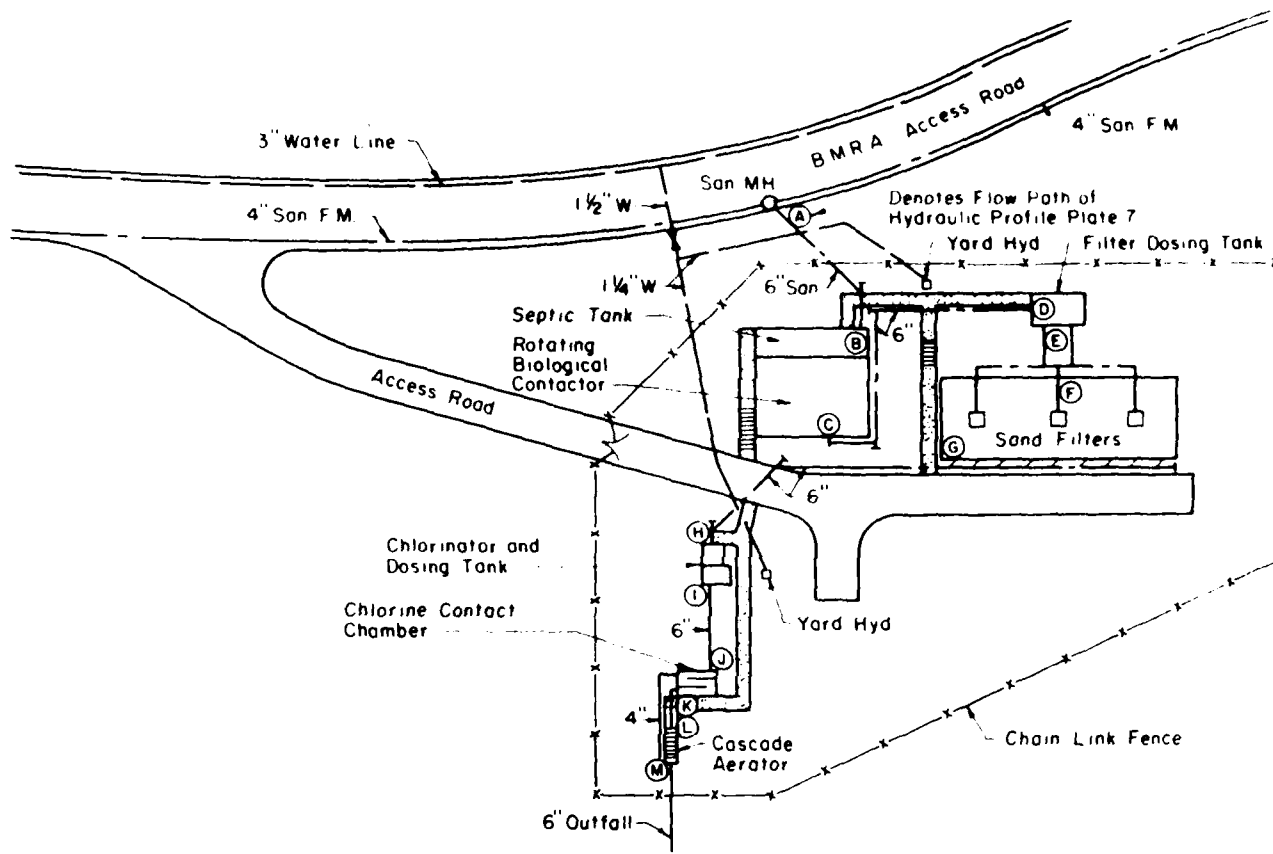
This treatment plant was designed by the Norfolk District Office of the Corps of Engineers for the Bolar Mountain Recreational Area. The plant was to begin operating in the summer of 1981. It is designed to serve three camping areas, one picnic area, a bathhouse, and two trailer dump stations. The facilities are for summer use only. The maximum flow was estimated to be 18,000 gpd. Using a mass diagram analysis of 3-day weekend flows, it was decided that an equalization tank with a capacity of 9700 gal could equalize the flow, resulting in an average flow to the treatment plant of 12,800 gal.

The negotiated NPDES permit for this treatment plant is as follows:

BOD:	7-day average, 20 mg/L 30-day average, 30 mg/L
TSS:	7-day average, 20 mg/L 30-day average, 20 mg/L
Fecal coliform:	7-day average, 200 MPN/100 ml 30-day average, 400 MPN/100 ml
DO:	minimum of 6.5 mg/L at all times
pH:	6 to 9
Chlorine residue:	between 1.0 to 2.0 mg/L

Initially, several alternatives were considered, including spray irrigation, physical-chemical treatment, RBC, and extended irrigation. The first cost of an RBC system was estimated to be higher than that of aeration and physical-chemical treatment, and less than that of spray irrigation. But the RBC process was adopted for this treatment plant because the Norfolk District Office considered it simpler to operate than extended aeration and physical-chemical treatment.

The treatment plant layout is shown in Figure 7. The raw sewage flows from two pumping stations into a septic tank for pretreatment (removal of solids), storage, and anaerobic digestion of sludge and scum. The sewage then enters the equalization tank by gravity. A bucket-fed RBC provides the biological treatment. The RBC effluent going through a clarifier, a splitter box, is discharged to any two of the three coarse sand filters for better removal of solids. From the splitter box, the RBC effluent can be recycled to the septic tank at low flows. An alternating dosing tank is used to feed the sand filters. Chlorination using dual tablet feed chlorinators followed by a chlorine tank disinfects the sewage, which flows over a 30 degree V-notch weir (with a flow receiver/recorder placed upstream of the V-notch weir) at the end of the chlorine contact tank. The sewage then flows down a cascade aerator to ensure that the effluent meets the requirement of a minimum DO concentration of 6.5 mg/L. A 6-in. drain then discharges the effluent into Lake Gathright through a submerged outfall in the hypolimnion layer of the lake.



Plant Layout

Figure 7. Bolar Mountain recreational area RBC plant layout.

Figures 8 and 9 show the RBC treatment system with the flow splitting and sludge return arrangements. Figure 10 shows the sand filters and their alternating dosing tanks for operating any two of the three filters while the third is resting. Figure 11 shows the chlorination system, the flow measurement/recording arrangement, and the cascade aerator before the effluent is discharged from the treatment plant. The plant unit capacities and design criteria are presented in Table 16.

The RBC unit, the final clarifier, and the equalization tank are in a building with louvers on three sides to provide natural ventilation. No heating is required since the plant is intended for summer use only.

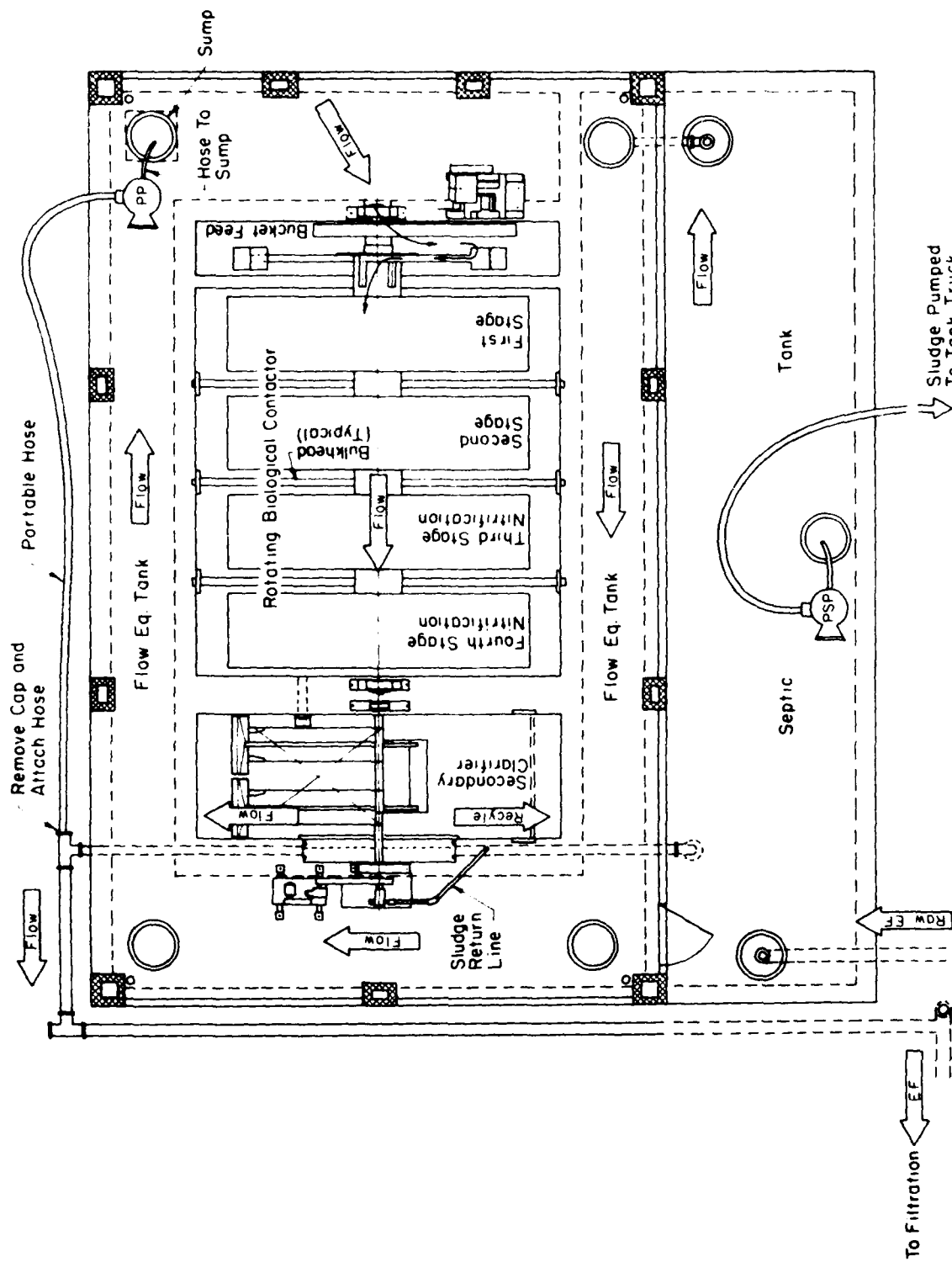
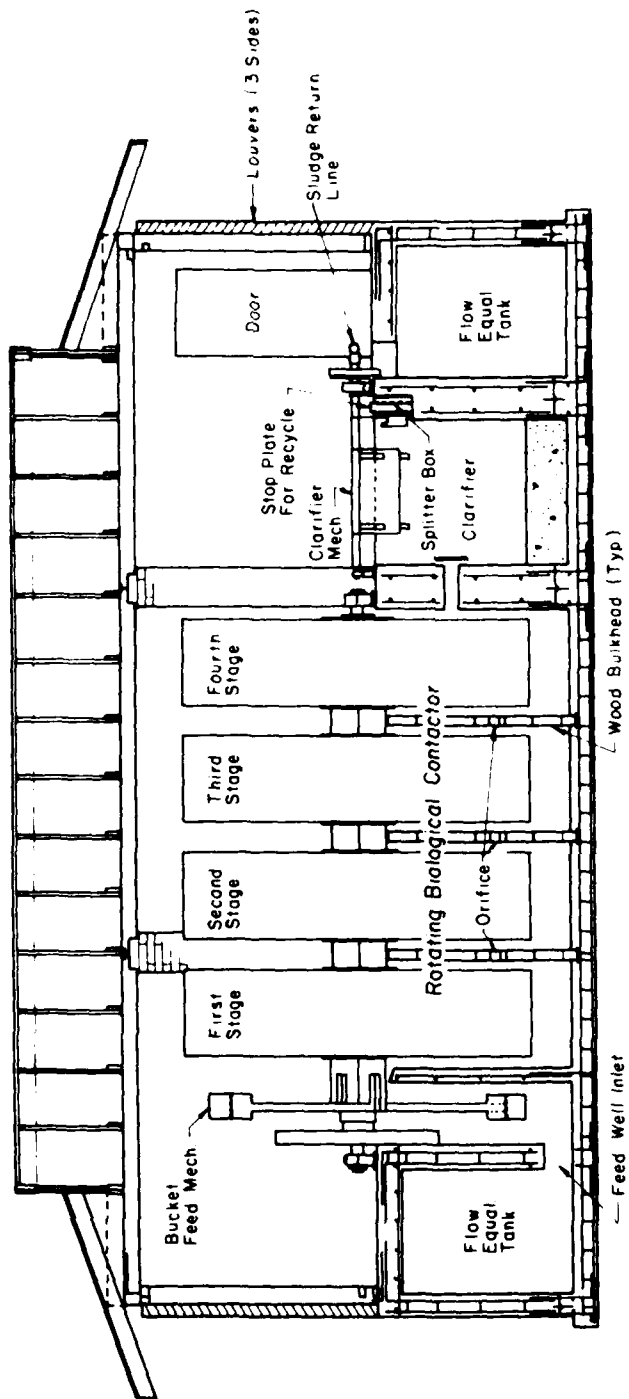
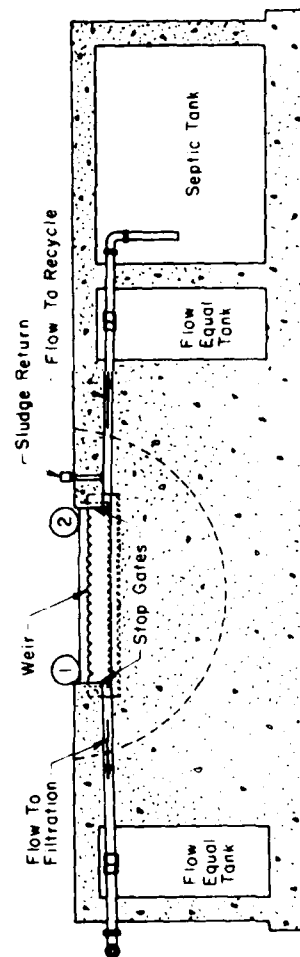


Figure 8. Biological unit.



Biological Treatment Section



Splitter Box & Weir Section

Figure 9. Biological treatment section, and splitter box and weir section.

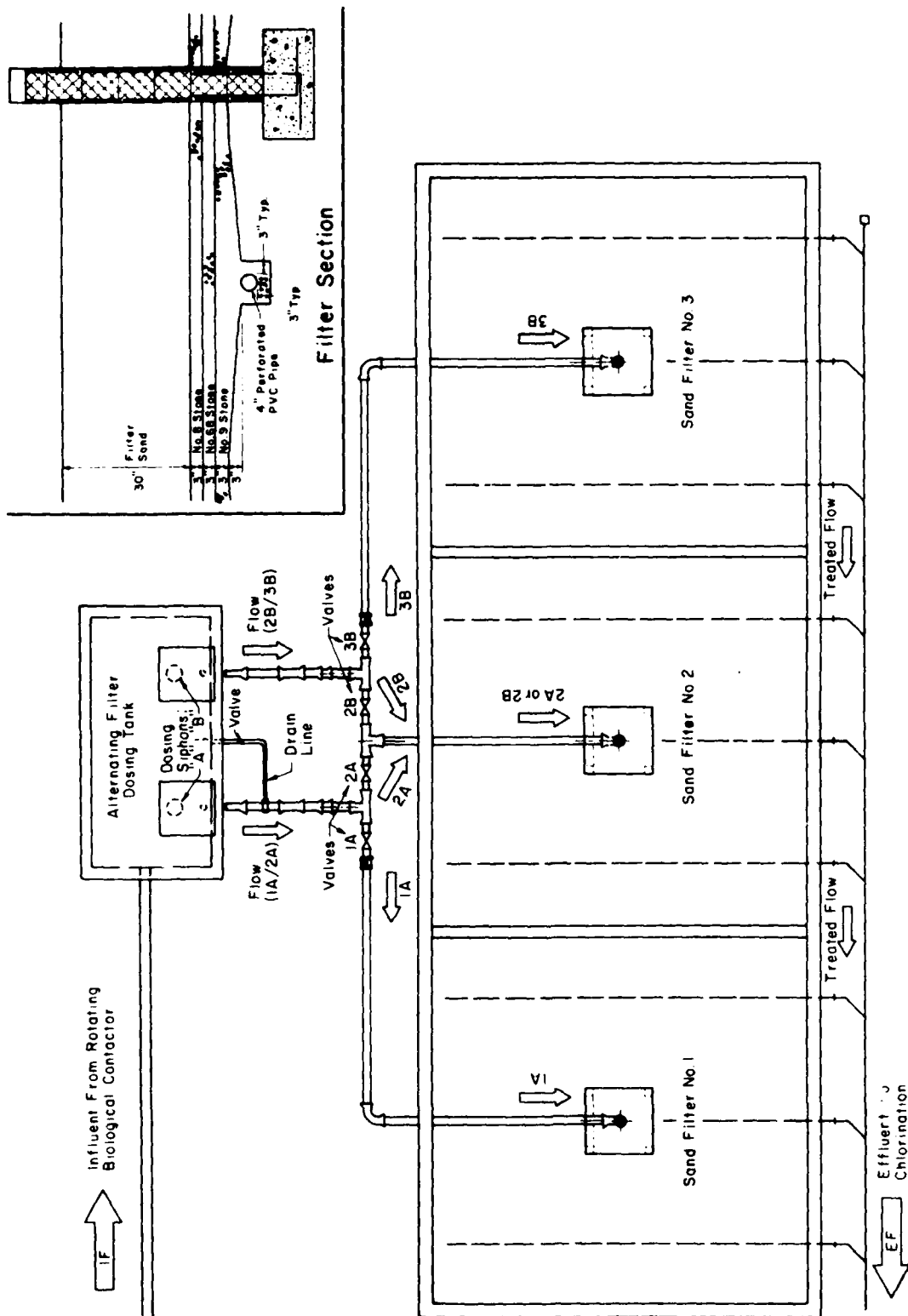
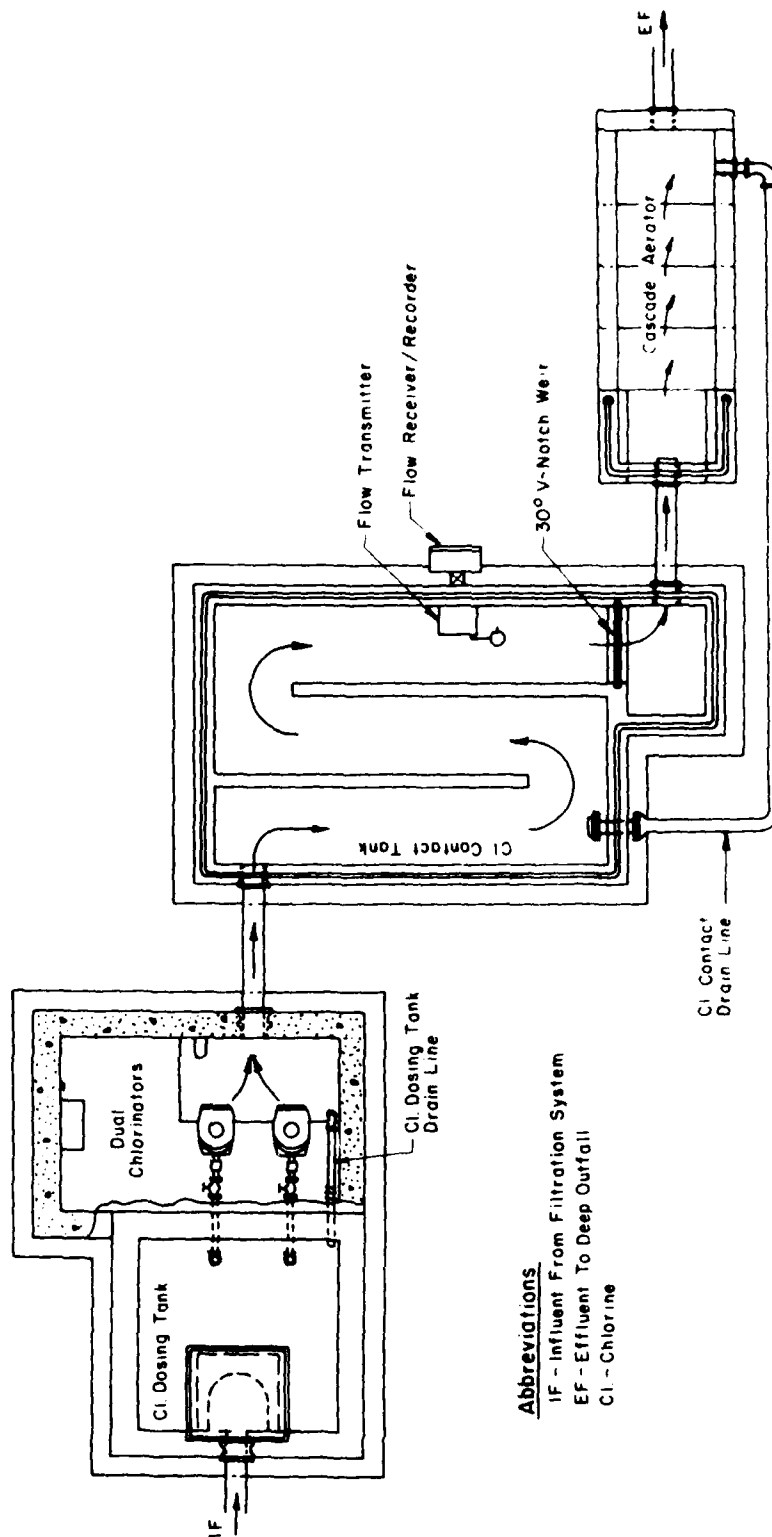


Figure 10. Sand filtration system.



Abbreviations
 IF - Influent From Filtration System
 EF - Effluent To Deep Outfall
 Cl - Chlorine

Figure 11. Chlorination system.

Table 16

Bolar Plant Unit Capacities and Criteria

Septic tank	9500-gal, 12-hr retention at a design flow of 13,000 gal, plus 25 percent sludge storage
Flow equalization tank	9700 gal
RBC	Influent soluble BOD ₅ , 194 mg/L; influent NH ₃ -N, 40 mg/L. Design temperature, 55°F (summer use only), and effluent total BOD ₅ , 20 mg/L after sand filtration. Effluent NH ₃ -N, 5 mg/L; 15-ft shaft; four-stage, 1.6 rpm, 48,000 sq ft media surface area
Secondary clarifier	56 sq ft, equipped with a rotating scoop sludge collector, Autotrol Model 63-1
Alternating filter dosing tank	4-in. siphon, 1150-gal dosing volume, 165 gpm maximum
Gravity sand filter (3)	22 ft x 22 ft each; effective size 0.3-0.5 mm. UC not greater than 4.0/4-in. perforated drain pipe
Chlorinator	Dual tablet feed chlorinators
Chlorine contact tank	10 ft x 6 ft effective channel area
Cascade aerator	2-ft, 1-in. weir and 1-in. depth of flow onto three steps, each 9.5-in. high and 9.0-in. wide

4 COMPARISONS OF RBC AND OTHER TREATMENT TECHNOLOGIES

This chapter: (1) considers in general terms the advantages and disadvantages of using RBCs instead of other alternatives; (2) provides design and cost information; and (3) describes specific characteristics of RBC systems. The objective is to provide more qualitative and quantitative information on which to base decisions about using RBCs.

In Tables 17 through 22, five treatment technologies in addition to RBC are considered: septic tanks/leaching fields or subsurface sand filters; extended aeration; facultative/aerated lagoon with sand filters; facultative/aerated lagoon with spray irrigation; oxidation ditch.

Design of a Typical Corps Recreational Area Sewage Treatment Facility

For each treatment technology, this discussion establishes a preliminary design so that the plants' unit capacities can be determined. All technologies meet general State effluent quality requirements. Specific effluent quality may be considered or omitted because of the special capability or limitation of a given technology. Note that the flow values of the typical Corps recreational area discussed in Chapter 2 (23,000 gpd weekend flow and 12,100 gpd weekday flow) are close to the flow values in EM 1110-2-501 (24,900 gpd weekend flow and 11,000 gpd weekday flow). Consequently, the EM's rates will be used for the design of all technologies in this chapter. The advantage is that an example of extended aeration design is already presented in detail on pp 8-24 to 8-39 of EM 1110-2-501. Corps district personnel involved in wastewater facility planning and design should be familiar with this manual. Using this design example and the flow values given should provide a good reference point against which other technologies can be compared.

Design Criteria Applicable to All Technologies

1. Flow:

Weekend flow.....	24,900 gpd (EM 1110-2-501, p 8-29)
Weekday flow (calculated).....	11,000 gpd (p 8-30)
BOD load.....	0.26 lb/100 gal (p 8-29)
NH ₃ -N.....	40 mg/L

2. Operation: Seasonal from April to end of September.

3. Monthly flow distribution:

June	100 percent	420,000 gal/month
July	100	420,000
August	100	420,000
September	42	176,400
April	10	42,000
May	21	88,200

Table 17

Septic Tank/Leaching Field or Subsurface Sand Filters

Advantages and Capability

Low capital cost and installation cost.

Very low operation and maintenance cost.

Skilled operation is not required.

No surface discharge.

Energy requirement minimal and at times zero.

Not affected by cold climate.

Small quantity of sludge generation requiring only infrequent cleanout for disposal.

Does not take up aboveground space.

No shutdown and restart problems.

Upset due to toxic loads not critical.

Load fluctuation not a problem to its operation. No effluent quality monitoring required.

Disadvantages and Limitations

Not applicable in areas with high groundwater table.

Not applicable in areas where percolation rate is too high or too low.

Cannot be located close to water supply wells, water course, or wet lands, except with State regulating agency.

If leaching fields fail (tend to be underdesigned), costly to repair.

Water reclamation is impossible.

4. Sewage temperature:

Summer, 75°F; early or late season, 48°F; average, 59°F.

5. Effluent requirements:

Total BOD₅ removal, 85%; or effluent total BOD₅, 20 mg/L.

Total SS removal 85%, or effluent total SS 20 mg/L.

NH₃-N, effluent NH₃-N: 2 mg/L in summer, 4 mg/L cold temperature (only considered for RBC and lagoon-spray irrigation because controlled nitrification and nitrogen removal are difficult to incorporate into the designs of other alternatives).

Table 18
Extended Aeration With Flow Equalization

<u>Advantages and Capability</u>	<u>Disadvantages and Limitations</u>
Capable of achieving secondary effluent quality and some nitrification.	Energy intensive.
Small area required.	Upset due to poor sludge settling in secondary clarifier not uncommon.
Available in package units.	Moderately affected by cold weather (ice, freezing).
Upset due to minor changes of organic loading, pH, temperature unlikely.	Higher capital, operation, and maintenance cost.
Sludge quantity small; not offensive.	Seasonal start requires considerable time and effort.
Treated effluent can be used for toilet flushing, pit privy, chemical toilet, dump waste dilution, or irrigation in water shortage area.	Upset due to excessive chemical toilet dumping likely.
	Moderate effort to maintain mechanical equipment.

Extended Aeration With Sand Filters

The design for extended aeration with sand filters is shown in EM 1110-2-501. There are two exceptions, however: the flocculation tank for phosphorus removal is omitted since phosphorus is not specified in State effluent requirements; the dual media filter is reduced with coarse sand filters after the final clarifier for effluent polishing. The survey for this study and other contacts with sewage treatment plant operators revealed that dispersed growth in extended aeration often results in the settling of solids or the carry-over of sludge in the clarifier. Adding coarse sand filters ensures that the effluent's quality meets BOD and SS requirements, but eliminates the expensive dual media filter with backwashing. Chlorine residue control is also easier with a more stable effluent.

The design is summarized in Figure 12 and Table 23.

Table 19

Facultative/Aerated Lagoon With Sand Filter for Effluent Polishing

Advantages and Capability

Capable of achieving moderate effluent quality (90% BOD removal).

Low capital and installation cost.

Low operation and maintenance cost.

Upset due to minor changes of organic loadings, pH, temperature unlikely.

Sludge quantity small, requiring only infrequent cleanout for disposal.

Able to tolerate a higher toxic load without upset (better than extended aeration).

Seasonal start is not a problem.

Treated effluent can be reused for flushing, pit privy, or chemical toilet dump dilution, or irrigation in water shortage area.

Disadvantages and Limitations

Large area required.

Operational problems in cold weather.

Moderate power costs.

Not suitable for areas with high groundwater table.

If shutdown at the end of season (in cold weather region), restart could cause odor problem for short time.

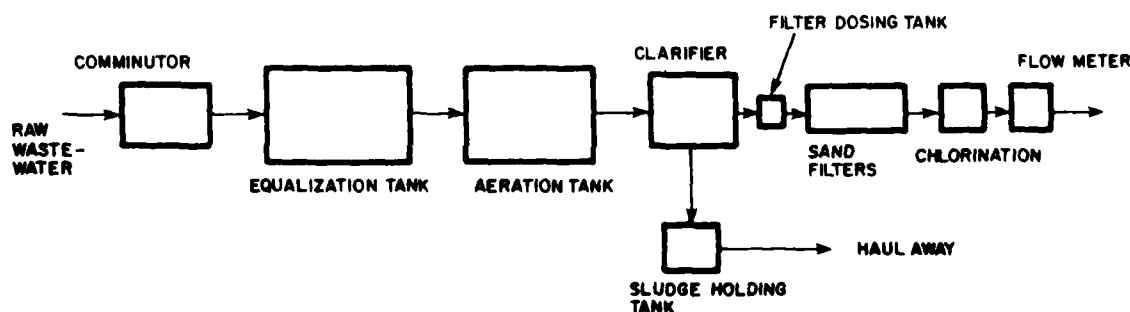


Figure 12. Extended aeration with sand filters.

Table 20
Oxidation Ditch

Advantages and Capability

Capable of achieving moderate effluent quality with some nitrification.

Upset due to minor changes of organic loading, pH, and temperature unlikely.

Low operation and maintenance cost.

Sludge quantity small, requiring only infrequent cleanout for disposal.

Able to tolerate a higher toxic load without upset.

Treated effluent can be used for toilet flusing, pit privy, or chemical toilet dump dilution, or irrigation in water shortage area.

Disadvantages and Limitations

Moderate skill in operation required if secondary effluent quality is to be obtained.

Large area required.

Moderate construction cost because of large volume of concrete works.

If shutdown at the end of season (in cold climate region) restart could cause odor problem for short time.

Facultative/Aerated Lagoon With Sand Filters

The design procedure for the facultative/aerated lagoon is similar to that shown in EM 1110-2-501, pp 8-16 to 8-20; however, the effluent from the lagoon goes into coarse sand filters for polishing, followed by chlorination and surface discharge. No holding pond after the lagoon is needed. The design flow is identical to that used in the extended aeration design, the monthly flow distribution has been described in the design criteria previously presented. Figure 13 is a flow diagram of the facultative/aerated lagoon. The design is summarized below.

Table 21
Land Treatment

Advantages and Capability

Low first cost.

Low skill for operation.

Low energy required for some favorable topography.

Crop production (may be more a liability than asset depending on site location).

Small quantity of sludge (only from the storage pond) -- requires only infrequent cleanout.

Seasonal shutdown and restart require minimal effort and time.

Disadvantages and Limitations

Problem with toxic load.

Large land area required.

Operational problem in cold weather.

Possible contamination of groundwater.

Odor and insect problems in summer prohibit public access to the treatment area -- a bigger or more costly problem because of size.

Many States require a minimum of secondary treatment before land application, which would be expensive.

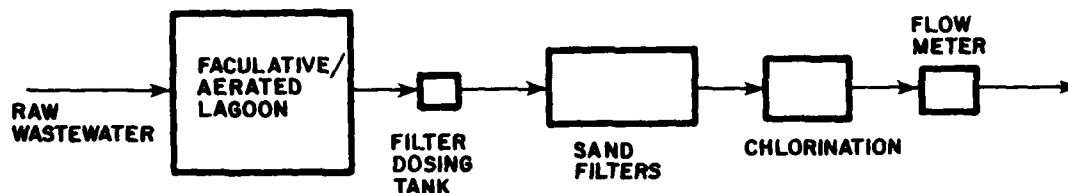


Figure 13. Facultative/aerated lagoon with sand filters.

1. Sizing of the lagoon:

- a. BOD, 250 to 300 mg/L.
- b. Design temperature in summer is 75°F. This temperature is used because the design procedure assumes the maximum oxygen demand is most critical to the design in the summer.
- c. BOD removal rate, $K_{20^{\circ}\text{C}} = 0.75/\text{day}$.

Table 22

RBC With a Septic Tank Serving Both Flow Equalization
and Sludge Treatment

Advantages and Capability

Capable of achieving secondary effluent quality.

Controlled nitrification can be achieved.

Small area required.

Available in package units.

Upset due to minor changes of organic loading, pH, temperature unlikely.

Sludge quantity small, requiring infrequent cleanout.

Treated effluent can be reused for toilet flushing, pit privy, or chemical toilet dump dilution, or irrigation in water shortage area.

No dispersed solids in effluent.

Disadvantages and Limitations

RBC has to be covered, and enclosures may need heating in very cold climate.

Moderate effort to maintain mechanical equipment.

- d. Temperature coefficient $\theta = 1.075$.
- e. Desired degree of treatment = 85 percent.
- f. Adjusted BOD removal rate constant:

$$\begin{aligned}
 K_t &= K_{20} \theta^{T-20} \\
 &= 0.75(1.075)^{23.9 - 20} \\
 &= 0.994/\text{day}.
 \end{aligned}$$

Table 23

Design Summary: Extended Aeration With Sand Filters

Comminutor: 45 gal/min capacity

Equalization tank: 20,000 gal volume (based on mass flow diagram analysis) 10 ft x 4.6 ft x 10 ft diameter.
Two blowers, each 35 cu ft/min air supply.
Two discharge pumps, 100 gal/min capacity.

Aeration tank: 15,000 gpd equalized flow or 24 hr detention.
Two blowers, each 55 cu ft/min air supply.

Clarifier: 300 gpd/sq ft or 4 hr retention for design flow of 15,000 gpd.
Surface area, 50 sq ft.

Alternating filter dosing tank: 4 in. siphon, dosing rate of 165 gpm,
maximum volume 1875 gal.

Coarse sand filters: three filters, 28 ft x 28 ft each; each with 30-in. layer of 0.3 to 0.5 mm. Effective sand size (UC not greater than 4), and 9-in. layer of graded stone, with 4 in. PVC underdrain.

Chlorination tank: 63 cu ft volume for 15 min detention at 300 percent of design flow. Dual tablet feed chlorinators.

Flow recorder/totalizer: 22-1/2-degree weir float operated flow recorder/totalizer

Sludge holding tank: 1500 gal (manufacturer recommends a holding tank volume equalizing 0.1 of aeration tank volume).

g. Detention time calculation:

$$\frac{S_e}{S_0} = \frac{1}{1 + K_t \cdot t} (1.2)$$

where 1.2 is seasonal correction factor for summer, S_e is effluent BOD concentration, and S_0 is initial BOD concentration.

$$0.15 = \frac{1.2}{1 + (0.994) t}$$

$$t = 7.0 \text{ days.}$$

The size is doubled to serve as a facultative pond using the aerator as a backup system for odor control.

$$\text{Volume of lagoon} = \frac{25,000 \text{ gal/day} \times 14 \text{ days}}{7.48 \text{ gal/cu ft.}}$$

$$= 46,800 \text{ cu ft.}$$

$$\begin{aligned} 2. \text{ Oxygen requirement} &= \frac{(1.15)(300 \times (0.85)(25,000)(8.34) \times 1.2}{10^6} \\ &= 73.3 \text{ lb/day} \end{aligned}$$

where 1.15 is fraction of BOD oxidized for energy (see EM 1110-2-501, p 8-17).

3. Surface aerator design, assuming oxygen saturation:

$$C_{sw} = 7.52 \text{ mg/L}$$

$$\alpha = 0.85$$

$$\text{Temperature} = 75^\circ\text{F}$$

$$\text{Minimum DO to be maintained in wastewater} = 1.0 \text{ mg/L}$$

$$\text{Rated aerator transfer efficiency} = 3.0 \text{ lb/hp-hr}$$

$$N = \frac{(3.0)(7.52-1)(0.85)(1.02)^{23.9-20}}{9.17}$$

$$= 1.96 \text{ lb O}_2/\text{hp-hr.}$$

$$\begin{aligned} 4. \text{ Horsepower requirement hp} &= \frac{73.7 \text{ lb O}_2/\text{day}}{1.96 \text{ lb O}_2/\text{hp-hr}} \times \frac{1 \text{ day}}{24 \text{ hr}} \\ &= 1.56 \text{ hp.} \end{aligned}$$

5. Mixing horsepower requirement, using 7.0 hp/million gal:

$$\begin{aligned} \text{Mixing horsepower} &= 7.0 \times \text{volume} \times 10^{-6} \\ &= 7 (25,000 \text{ gal/day} \times 14) \times 10^{-6} \\ &= 2.45 \text{ hp; use 3 hp.} \end{aligned}$$

6. Determination of physical dimension of aerated lagoon (see Figure 14):

$$\begin{aligned} \text{Length/width ratio} &= 1:1 \\ \text{Side slope ratio} &= 3:1 \\ \text{Depth of lagoon} &= 6 \text{ ft} \\ \text{Volume} &= 46,800 \text{ cu ft.} \\ x &= 68.5 \text{ ft} \\ y &= 104.5 \text{ ft} \\ \text{Land area } (Y + 12)^2 &= 13,572 \text{ sq ft or 0.31 acre.} \end{aligned}$$

7. Haplon lagoon lining, area = 14,000 sq ft.

8. Alternating filter dosing tank = 4-in. siphon identical to that of the extended aerated system. Volume = 1876 gal.

9. Coarse sand filters: three filters identical to those of the extended aeration system; 28 ft x 28 ft each.

10. Chlorination tank: 63 cu ft -- identical to that of the extended aeration system.

11. Flow recorder/totalizer: 22-1/2-degree weir and float-operated flow recorder/totalizer identical to that of the extended aeration system.

Facultative/Aerated Lagoon With Land Treatment (Spray Irrigation)

A facultative/aerated lagoon can use spray irrigation for final disposal of the effluent instead of discharging to a water course after the sand filter polishing. When the recreational area is in seasonal use -- from April to the end of September -- a holding pond stores the effluent. Taking both precipitation and evaporation into consideration, the spray operation can be done from March until the end of November. Figure 15 is a flow diagram of the process. The design is summarized below.

1. Size of lagoon: 46,800 cu ft, with a 3-hp mixing requirement; land area of 0.31 acre; and Hapolon lining of 14,000 sq ft -- all identical to that of the lagoon sand filter systems.

2. Chlorination tank: 63 cu ft, identical to that of the lagoon-sand filter system.

3. Flow recorder/totalizer: 22-1/2-degree weir, and float-operated flow recorder/totalizer identical to that of the lagoon/sand filter system.

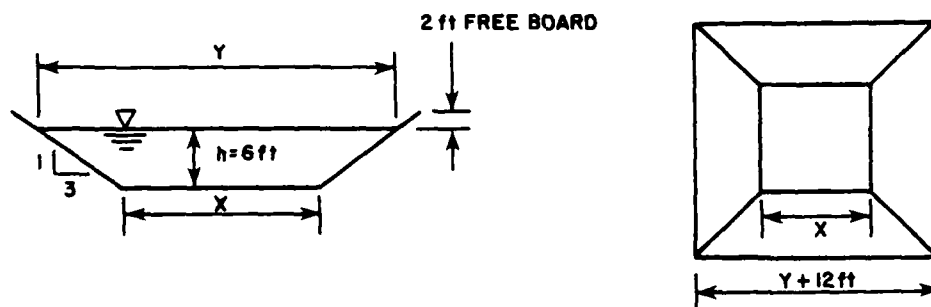


Figure 14. Size of aerated lagoon.

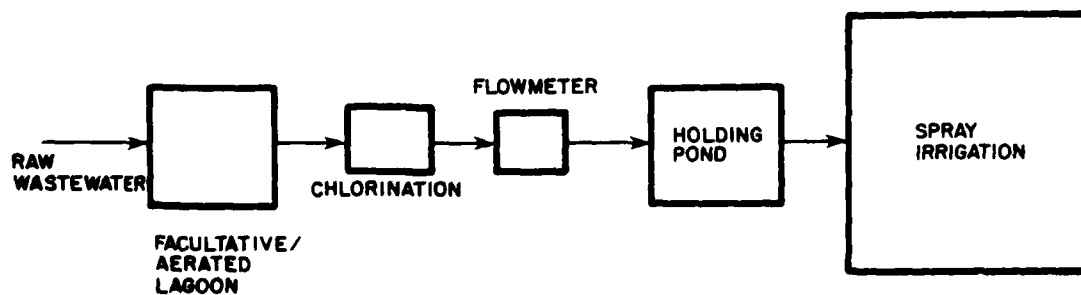


Figure 15. Facultative/aerated lagoon with land treatment.

4. Holding pond sizing:

Using the precipitation and evaporation data provided in the design example of facultative/aerated lagoon in EM 1110-2-501, and the sewage inflow during the season for this design, the calculation of the pond size is shown in Table 24.

Storage volume (from Table 24) = 42,450 gal = 5675 cu ft.

The holding pond's minimum depth should be 2 ft at all times. For a 6-ft deep pond (4-ft storage depth), the dimensions are $5675 \div 4 = 1419$ sq ft. If length-width ratio = 1:1, $38 \text{ ft} \times 38 \text{ ft} = 1444$ sq ft or 0.033 acre.

5. Hillside spray area requirements:

$$\begin{aligned}\text{Assume weekly volume} &= \frac{1,770,000 \text{ gal}}{32 \text{ wks}} \\ &= 55.312 \text{ gal/wk.}\end{aligned}$$

Spray rate: use 1 in./acre/wk = 27,152 gal/acre/wk (at this rate $\text{NH}_3\text{-N}$ concentration at the effluent is expected to be < 2 mg/L according to EPA 430/9-74-003).⁴

$$\begin{aligned}\text{Therefore, area of spray} &= \frac{55,312.5 \text{ gal/wk}}{27,152 \text{ gal/acre/wk}} \\ &= 2.04 \text{ acres.}\end{aligned}$$

With a buffer zone, a total of 3.0 acres would be required.

Oxidation Ditch With Sand Filters

The oxidation ditch, using a long-term aeration basin, is another version of the extended aeration system described previously. Figure 16 is a flow diagram of the process. The design is summarized below.

1. The comminutor has a 45 gal/min. capacity, identical to that of extended aeration system. Two approaches can be taken in designing the capacity of the oxidation ditch (Figure 17).

a. Eckenfelder's approach, outlined in EM 1110-2-501 (Chapter 7), can be used with the following assumptions:

- (1) Desired BOD removal = 85 percent.
- (2) Mixed liquor volatile suspended solids (MLVSS) concentration, $X_v = 4200$ mg/L.
- (3) Degradable fraction of MLVSS, $f' = 0.53$.
- (4) Endogenous respiration rate, $b = 0.075 \text{ day}^{-1}$.

⁴ Cost of Land Treatment Systems, EPA 430/9-73-003 (EPA, 1974).

Table 24

Calculation of Storage Pond Capacity
(All Units in Gallons)

Month	Waterborne Inflow	Precip.	Evapor.	Net Inflow	Sum of Flow	Spray Volume	Sum of Spray	Net Flow	Storage Capacity
Jan	0	29,000		29,000	29,000	0	0	+29,000	-75,075
Feb	0	61,100		61,100	90,100	0	0	+61,100	-13,975
Mar	0	32,900		32,900	123,000	110,625	110,625	-77,725	-91,700
Apr	42,000	29,200	68,400	2800	125,800	221,250	331,875	-218,450	-310,750
May	88,200	84,800	64,400	108,600	234,400	221,250	553,125	-112,650	-422,800
Jun	420,000	25,400	89,300	356,100	590,500	221,250	774,375	+134,850	-287,950
Jul	420,000	34,200	89,600	364,600	955,100	221,250	995,625	+143,350	-144,600
Aug	420,000	58,500	70,200	408,300	1,363,400	221,250	1,216,875	+187,050	(+42,450)
Sep	176,400	70,000	67,600	178,800	1,542,200	221,250	1,438,125	-42,450	0
Oct	0	115,800		115,800	1,658,000	221,250	1,659,378	-105,450	-105,450
Nov	0	63,700		63,700	1,721,700	110,625	1,770,000	-46,925	-152,375
Dec	0	48,300		48,300	1,770,000	0	1,770,000	+48,300	-104,074

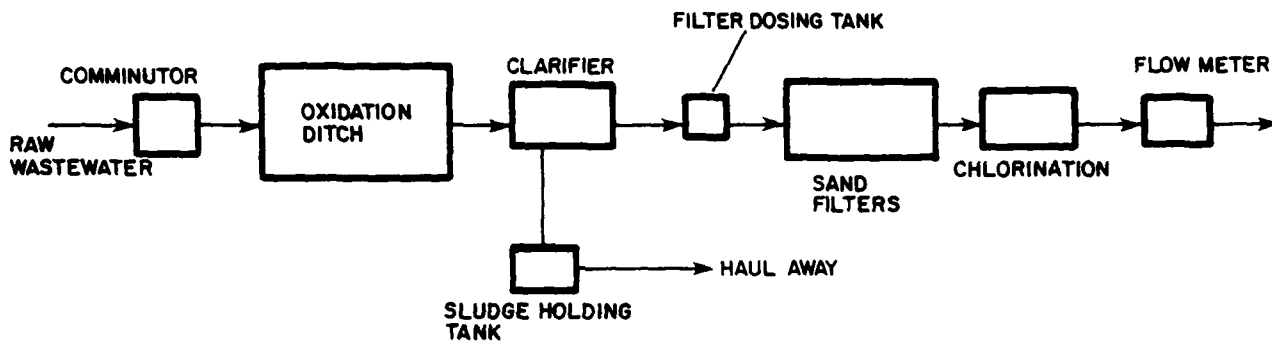


Figure 16. Oxidation ditch with sand filters.

(5) Fraction of BOD oxidized for energy, $a' = 0.56$.

(6) Size of ditch, $V = \frac{a' (1-0.85) \text{ BOD}_{\text{influent}} \times Q_{\text{avg}}}{X_v \cdot (f') \cdot b}$

$$= \frac{0.56(0.15)250(105,000 \text{ gal/wk})(1)}{4200(0.53)0.075(7)}$$

$$= 11,824 \text{ gal}$$

$$= 12,000 \text{ gal or } 1604 \text{ cu ft.}$$

This approach does not provide equalization (using the average daily flow), and the ditch size is underestimated for fluctuating flows.

b. The other approach, recommended by manufacturers during a telephone survey, uses design criteria of 15 lb BOD/1000 cu ft volume and a minimum of 18 hours detention time. Of the 15,000 gpd average daily flow, it is assumed that 12,000 gal come in a 12-hr period or equivalent to a flow of 24,000 gpd:

$$\text{Size of ditch, } V = \frac{24,000 \times 250 \times 8.34}{10^6(15)}$$

(aeration volume)

$$= 3300 \text{ cu ft}$$

$$\text{Detention time} = \frac{3300 \times 7.48 \text{ 24}}{24,000}$$

$$= 24.7 \text{ hr} > 18 \text{ hr minimum.}$$

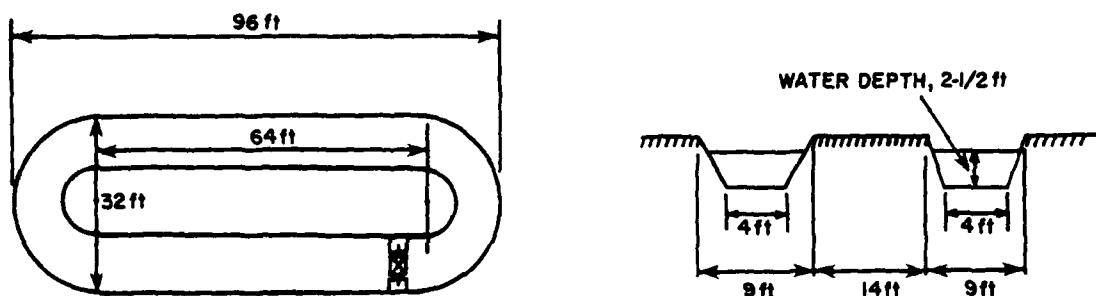


Figure 17. Capacity of oxidation ditch.

The manufacturer's approach is conservative, but is more acceptable for the fluctuating flow which is characteristic of the typical Corps recreational area. (With the design flow rate at 24,000 gpd, only slightly smaller than the weekend flow of 25,000 gpd, no equalization is required.)

2. Rotor; using a criterion of 13,000 gal/ft for cage rotor in a lined ditch:

$$\begin{aligned} \text{Mixing requirement} &= \frac{3300 \times 7.48}{13,000} \\ &= 1.9, \text{ or about } 2 \text{ ft.} \end{aligned}$$

$$\begin{aligned} \text{Oxygenation capacity} &= \frac{15,000 \times 250 \times 8.34 \times 2.34}{10^6 \times 24} \\ &= 3.1 \text{ lb/hp} \end{aligned}$$

where 2.35 is a conversion factor specifically for oxidation ditch application.

A 3-ft, 3-hp cage rotor should be used at 1.03 lb/hp/ft, 60 rpm, and 5.6-in. immersion.

3. Clarifier; using 300 gpd/sq ft overflow rate:

$$\begin{aligned} \text{Surface area} &= \frac{24,000}{300} \\ &= 80 \text{ sq ft.} \end{aligned}$$

4. Sludge return pump: air-lift pump, returning rate 50 to 150 percent of design gpm, or 25 gpm.

5. Three-in. sludge air lift and 3-in. scum air lift. All other units -- alternating filter dosing tanks, coarse sand filters, chlorination tank, flow recorder/totalizer, and sludge holding tank -- are the same size as in extended aeration system.

Rotating Biological Contactor With Sand Filters

This treatment system and the lagoon/spray irrigation system are the only alternatives considered for which nitrification can be designed or nitrogen ($\text{NH}_3\text{-N}$) removal to less than 2 mg/L of $\text{NH}_3\text{-N}$ in the effluent can be expected. This aspect of the system is important for locations where NPDES permits specify low $\text{NH}_3\text{-N}$ in the effluent in order to produce receiving water of high quality. While some nitrification can take place in the extended aeration, oxidation ditch, and lagoon/sand filter systems, the degree of nitrification, and therefore the specified effluent $\text{NH}_3\text{-N}$ concentration, is never assured. Figure 18 is a flow diagram of the RBC process. The design is summarized below.

1. Septic/equalization tank: 20,000 gal, as in extended aeration system; add 25 percent storage volume, total $20,000 \times 1.25 = 25,000$ gal.

2. Size of RBC:

a. BOD removal from a septic tank, according to Wastewater Treatment Systems for Safety Rest Areas, is about 40 to 45 percent.⁵ Assume 40 percent BOD removal.

Septic tank effluent BOD = 0.6×250

= 150 mg/L mostly soluble.

Increase in soluble BOD_5 due to solubilization of sludge solids in septic tank = 40 mg/L.

Soluble BOD = $150 \text{ mg/L} \times 93 \text{ percent soluble} + 40 \text{ mg/L}$

= 180 mg/L.

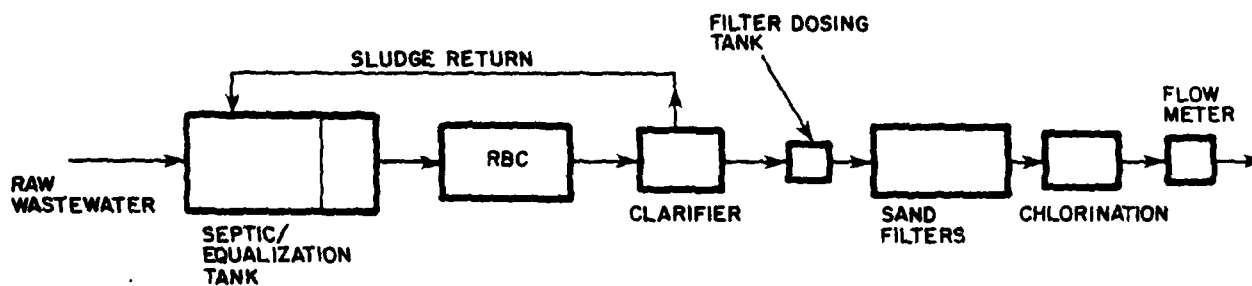


Figure 18. RBC with sand filters.

⁵ Wastewater Treatment Systems for Safety Rest Areas, FHWA-RD-77-107 (prepared for FHWA by U.S. Army Engineer Waterways Experiment Station [WES], September 1977), Figure 11-2.

This concentration is higher than the 133 mg/L soluble BOD cited in Wastewater Treatment Systems for Safety Rest Areas, p 11-12.

b. Early or late season temperature, 48°F.

BOD removal of 1.2 gpd/sq ft, allowed from Figure C-1 of Autotrol Manual,⁶ to remove SBOD₅ from 180 mg/L to 15 mg/L, and with temperature correction of 0.825:

$$\begin{aligned} \text{HL-BOD} &= 1.2 \times 0.825 \\ &= 1.0 \text{ gpd/sq ft.} \end{aligned}$$

Nitrification of 1.0 gpd/sq ft, allowed from Figure C-6 of the Autotrol Manual, to remove NH₃-N from 40 mg/L to 4 mg/L with temperature correction of 0.7:

$$\begin{aligned} \text{HL-NH}_3 &= 1 \times 0.7 \\ &= 0.7 \text{ gpd/sq ft.} \end{aligned}$$

$$\begin{aligned} \text{Overall hydraulic loading} &= 1 / \left(\frac{1}{1.0} + \frac{1}{0.7} \right) \\ &= 0.41 \text{ gpd/sq ft.} \end{aligned}$$

c. Mid-season temperature, 75°F.

Similar procedure gives overall hydraulic loading of 0.48 gpd/sq ft. Therefore, lower temperature controls the design.

$$\begin{aligned} \text{d. Surface media requirement} &= \frac{15,000 \text{ gpd}}{0.41 \text{ gpd/sq ft}} \\ &= 36,585 \text{ sq ft.} \end{aligned}$$

The size of the first stage RBC, based on SBOD₅ loading of

$$\frac{180 \times 8.34 \times 15,000 \times 1,000}{36,585 \times 10^6} = 0.615 \text{ lb/1000 sq ft-day}$$

and from Figure C-2 of the Autotrol Manual is 16 percent. However, an expanded first stage RBC should be used to accept septic tank effluent. For example, Autotrol has a Model 621-154: one 15-ft shaft, four-stage, 3.2-in.-diameter unit, which provides 38,700 sq ft. The baffle between the first and second stages can be removed to give a three-stage RBC unit (50 percent first stage, 25 percent second stage, and 25 percent third stage -- all with standard media).

$$3. \text{ Clarifier: } \frac{15,000 \text{ gpd}}{300 \text{ gpd/sq ft}} = 50 \text{ sq ft surface area. Other treatment units}$$

⁶ Wastewater Treatment System: Autotrol Corporation Design Manual (Autotrol Corporation, 1979).

-- i.e., alternating filter dosing tank, coarse sand filters, chlorination tank, and flow recorder/totalizer -- are identical to those of the extended aeration system (except no sludge holding tank is required in the RBC sand filter system).

Septic Tank/Leaching Field

Although this treatment system can be applied only to locations where subsurface discharge is allowed and the discharged effluent can be of very poor quality, the system's components are determined here so that cost comparison with other alternatives can be presented later. The design procedure is strictly according to EM 1110-2-501:

1. Septic tank:

$$\begin{aligned} \text{Septic tank volume, } V &= 1125 + 0.75 \times Q_{\text{avg}} \\ \text{(including sludge volume)} &= 1125 + 0.75 (15,000) \\ &= 12,375 \text{ gal} > 10 \text{ hr minimum detention time} \\ &< 24 \text{ hr based on average flow} \end{aligned}$$

Use a 15,000-gal tank with two compartments.

2. Dosing tank with siphon: 4-in. siphon, volume 1875 gal.

3. Trench system: this leaching system is preferred over the subsurface sand filters because it has less chance of failure.

$$Q_a, \text{ application rate} = \frac{5}{\sqrt{t}} = \frac{5}{\sqrt{t}} = 2.2 \text{ gpd/sq ft}$$

where t is percolation rate, assumed to be 5 min/in.

$$\begin{aligned} \text{Trench bottom area} &= \frac{1.25 Q}{Q_a} \\ &= \frac{1.25(15,000)}{2.2} \\ &= 8523 \text{ sq ft.} \end{aligned}$$

Cost Comparison of Alternatives

For each of the treatment system alternatives, Tables 25 through 30 give cost estimates for all plant units, including installation. With very few exceptions the costs were obtained from a telephone survey of manufacturers' representatives in June 1981. Costs for site preparation, excavation, and local labor vary from region to region. The costs given here generally reflect expenses in the northeastern United States. The cost of land is not considered, nor is the cost of any pumping stations needed to deliver the sewage to the treatment plant.

For a 2-ft wide trench:

$$\begin{aligned}\text{Length} &= \frac{8523}{2} \\ &= 4261 \text{ sq ft.}\end{aligned}$$

Field area with drainlines on 6-ft centers:

$$\begin{aligned}\text{Area} &= 4261 \times 6 \\ &= 25,566 \text{ sq ft.}\end{aligned}$$

Cost estimates for the various treatment alternatives are summarized in Table 31.

Characteristics of RBC Systems for Corps Recreational Areas

System Start-Up

Normally, it takes from 1 to 2 weeks to establish enough biomass on the media to provide adequate carbonaceous BOD removal. An additional 2 weeks are required to establish full nitrification in the summer, provided that the RBC unit is designed for nitrification. Start-up in the winter takes longer, and it is not unusual for nitrification to take 1 month or more. The RBC tankage must be drained at the end of a season. If this is not done, the upper part of the media sheds the dried-up biomass in the off-season, while the bottom part still has the biomass on it. This creates an unbalanced load when the RBC unit is started again the next season, often leading to mechanical failure.

The time needed for starting an RBC system is about the same as for lagoons, but shorter than for extended aeration and oxidation ditch. (Extended aeration and oxidation systems applied to recreational areas for seasonal use often have problems during start-up because of the slow accumulation of active culture in the systems.)

Load Fluctuation and Organic Shock Loading

Flow fluctuations can be significant in recreational areas. Diurnal flow variations, daily flow variations during the week, and seasonal fluctuations cause problems for biological treatment systems. The survey of existing systems in recreational areas revealed many plant upsets caused by flow fluctuations -- even among the extended aeration plants which have a built-in flow equalization capacity. RBCs can have severe problems with flow and organic load fluctuations. This is to be expected because, as semi-plug flow systems, RBCs have a very low equalization capacity. However, RBC manufacturers have long recognized this problem. All RBC systems that are operating or being built in recreational areas have equalization tanks.

These tanks effectively reduce the peak flows and organic shock loads so that plants now operating do not have problems with flow fluctuations. A mass flow analysis of a week's flow in peak seasonal use normally determines the required equalization capacity so that a near-uniform load can be applied to

Table 25

Septic Tank/Leaching Field System

1. Installation cost:

Septic tank, 15,000 gal, two compartments, precast reinforced concrete, 4000 psi test, installed (within 100 mi of supplier).....	\$7484
Trench, 2-ft wide, on 6-ft centers, 4261 ft.....	10,000
Dosing siphon, installed.....	1000
	<u>\$18,484</u>
Contingency, 10 percent installation cost.....	\$1848
Total.....	<u>\$20,332</u>

2. O&M cost (annual)

Sludge hauled away by contractor once/5 yrs; volume, 10,000 gal; \$500 for a distance within 50 mi. Annual cost.....	\$100
Labor, about 2 hr/wk.....	520
Total.....	<u>\$620</u>

3. Land requirement = 0.6 acre

the RBC system throughout the week. Flows for the entire year should not be included in the mass flow analysis for RBC systems to be used seasonally. The result would be a huge equalization capacity.

Although the unit size has to be larger for seasonally operated plants, the cost analysis above shows that the first cost is not very high for a typical Corps recreational area treatment facility. The savings of operation and maintenance costs in seasonal operation can easily balance the savings of the first cost of providing a smaller treatment plant (with a larger equalization tank). This is primarily because of the scale of economics involved -- reducing the size of such a small treatment plant matters little, but savings in operation and maintenance costs for seasonal operation are significant.

With one exception, existing RBC systems documented in this report use multiple compartment septic tanks for flow equalization. The septic tank is also for pretreatment (settling of solids) and storage of biological solids returned from the RBC clarifier. This minimizes the sludge handling problem, which will be addressed later in this chapter.

Table 26

Extended Aeration/Sand Filters

1. Installation cost

Comminutor, Aero-flow, 140 gal/min, plus a 20,000-gal equalization tank with two blowers supplying 70 cu ft/min of air.....	\$30,000
15,000-gal aeration tank, two blowers, 55 cu ft/min each (Aero-flow).....	30,000
Clarifier.....	5000
Chlorination.....	2000
Sludge holding tank.....	3500
Flowmeter/totalizer.....	2752
Screen fencing, electrical, dosing tank, pipe fitting, concrete footing.....	10,000
Three coarse sand filters, 28 ft x 28 ft each.....	<u>15,000</u>
	\$98,252
10 percent contingency.....	9825
Total.....	<u>\$108,000</u>

2. Annual O&M cost

Material & repairs.....	\$750
Sludge hauled away by contractor once/yr.....	250
Power cost.....	1490
Labor, 3 hr/day.....	5460
Total.....	<u>\$7950</u>

3. Land requirement = 5000 sq ft

Table 27

Facultative/Aerated Lagoon and Sand Filters

1. Installation cost

Lagoon with plastic liner and aerators.....	\$61,646
Three sand filters, 28 ft x 28 ft each.....	15,000
Chlorination.....	4000
Screen fencing, electrical dosing tank, pipe fitting, concrete footing.....	12,500
Flowmeter/totalizer.....	2752
	<u>\$95,898</u>
10 percent contingency.....	9590
Total.....	<u>\$105,488</u>

2. Annual O&M Cost

Materials & repairs.....	\$600
Sludge hauled away by contractor once/yr.....	250
Power cost.....	688
Labor, 1 hr/day.....	1820
Total.....	<u>\$3358</u>

3. Land requirement = 0.5 acre

Design Factors

It has become common practice to consider both the hydraulic load and the organic load in sizing an RBC unit. Similarly, both hydraulic load and $\text{NH}_3\text{-N}$ load are used for nitrification design.

For BOD removal, SBOD_5 is a better parameter to consider in design. Knowing the influent SBOD_5 concentration, a designer can enter design curves or tables prepared by RBC manufacturers to determine the allowable hydraulic loading in gallons per day per square foot. The media's surface area is then determined by dividing the designed equalized flow rate by the hydraulic loading. Because organic solid solubilization takes place in the septic equalization tank -- primarily through anaerobic digestion -- more SBOD_5 is added to the sewage, making the RBC unit influent stronger than normal in soluble BOD.

For nitrification, the SBOD_5 must be reduced to 15 mg/L or less before the nitrifying bacteria can be established and maintained well on the media. The design procedure therefore includes first sizing the RBC unit to reduce

Table 28

Facultative/Aerated Lagoon and Spray Irrigation

1. Installation cost

Lagoon with plastic liner.....	\$61,646
Chlorination.....	4000
Holding pond, 4773 cu ft.....	11,000
Spray irrigation (site clearing, solid set sprinkling buried, collection) 3.5 acres.....	10,400
Flowmeter/totalizer.....	2752
Screen fencing, electrical, pipe fitting, concrete footing.....	12,500
	<u>\$99,546</u>
10 percent contingency.....	9955
Total.....	<u>\$109,501</u>

2. Annual O&M cost

Materials & repairs.....	\$750
Sludge hauled away by contractor once/yr.....	250
Power cost (spray irrigation depends primarily on gravity flow).....	750
Labor, 1-1/2 hr/day.....	2730
Total.....	<u>\$4480</u>

3. Land requirement = 4.0 acres including buffer zone

the $SBOD_5$ to 15 mg/L, and then using design curves or tables to determine the media area requirements at the later stages for nitrification.

Most design curves or tables only predict nitrification with effluent NH_3-N concentration down to 1.0 mg/L. For practical purposes, this removal is adequate since most NPDES permits do not require effluent NH_3-N concentrations lower than 2 mg/L in the summer and 4 mg/L in the winter.

Table 29
Oxidation Ditch and Sand Filters

1. Installation cost

Site preparation, excavation and oxidation ditch, concrete lined (6-in.) at \$300/cu yd.....	\$38,000
Three-hp, 3-ft cage roter, 1 speed.....	9500
Clarifier with air-lift pump for sludge return pump.....	7610
2-ft weir gate.....	1985
Sludge holding tank.....	3500
Chlorination.....	4000
Three coarse sand filters, 28-ft x 28-ft each.....	15,000
Flowmeter/totalizer.....	2752
Screen fencing, electrical, dosing tank, pipe fitting, concrete footing.....	12,500
	<u>\$92,862</u>
10 percent contingency.....	9286
Total.....	<u>\$102,148</u>

2. Annual O&M cost

Material & repairs.....	\$750
Sludge hauled away by contractor once/yr.....	250
Power cost.....	1000
Labor, 3 hr/day.....	5460
Total.....	<u>\$7460</u>

3. Land requirement = 8000 sq ft

Effect of Low Temperatures

Low temperature inhibits biological reactions and reduces the effectiveness of treatment in all biological treatment plants, including RBC systems. Temperature correction factors are provided in manufacturers' design curves and tables for both BOD removal and nitrification so that RBC units can be sized properly for low temperature application. A sewage temperature near freezing considerably slows, but does not stop, the treatment. (The Indiana Dune Lakeshore RBC treatment plant operates year-round.) A fiberglass cover

Table 30
RBC and Sand Filters

1. Installation cost

Septic equalization tank, 25,000 gal.....	\$10,500
RBC, 15-ft shaft, 38,700 sq ft media, mechanical drive.....	41,500
RBC fiberglass enclosure.....	5500
RBC clarifier & chlorination.....	16,200
Screen fencing, electrical, dosing tank, pipe fitting, concrete footing.....	10,000
Three coarse sand filters, 28 ft x 28 ft each.....	15,000
Flowmeter/totalizer.....	2752
	<u>\$101,452</u>
10 percent contingency.....	10,145
Total.....	<u>\$111,597</u>

2. Annual O&M cost

Material & repairs.....	\$600
Sludge hauled away by contractor once/5 yrs., volume 15,000 gal; \$750 for a distance within 50 mi. Annual cost.....	150
Power cost.....	920
Labor, 2 hr/day.....	3640
Total.....	<u>\$5310</u>

3. Land requirement = 5000 sq ft

or a roofed structure is provided for all existing RBC systems in recreational areas to prevent excessive heat loss (but mainly to protect the culture from washout by precipitation and to protect the media from sunlight). There should be louvers on the cover to provide ventilation so that condensation can be eliminated.

Table 31

Summary of Alternatives

	Installed Cost	Seasonal O&M Cost	Land Requirement	Seasonal Power Consumption, kWh
Septic tank/leaching field	\$20,332	620	0.6 acre	0
Extended aeration/sand filters	108,000	7950	5000 sq ft	22,000
Facultative/aerated lagoon and sand filters	105,488	3358	0.5 acre	10,200
Facultative/aerated lagoon and spray irrigation	109,501	4480	4.0 acres	11,000
Oxidation ditch and sand filters	102,148	7460	8000 sq ft	15,000
RBC and sand filters	111,597	5310	5000 sq ft	13,800

Effective Rotation Speed

RBC manufacturers have found that when the peripheral speed of the rotating media is kept at or above 60 ft/min, the RBC operates as designed. However, oxygen transfer limitation and nutrient mass transfer limitation may occur if this speed is not maintained. This is important particularly for the RBC unit accepting septic tank effluents which contain very little or no dissolved oxygen.

Sludge Biosynthesis

RBC manufacturers indicate that 0.2 lb of biological sludge is generated for every pound of BOD₅ removed in an RBC system. Assuming a specific gravity of 1.04 and a percent solid of 2.0 percent for the biological solids, the 0.2 lb/lb BOD removal is equivalent to 0.02 gal/lb of BOD removal.

RBC Clarifier Requirement

For the small RBC treatment system typical in recreational areas, it is more appropriate to design the clarifier conservatively. A hydraulic loading between 300 gpd/sq ft to 600 gpd/sq ft is recommended. Since an RBC system contains very low suspended biological solids in its effluent, the solid loading rate is very small. Consequently, it is relatively unimportant to consider solid rate. In other words, hydraulic loading controls the design of RBC clarifiers.

Sludge Characteristics

The biological sludge generated from an RBC unit for carbonaceous BOD removal generally settles well. While quantitative data on sludge density and sludge thickening properties are scarce, the sludge volume is estimated to be 0.02 gal/lb of BOD removed. Nitrifying bacteria tend to settle poorly. Therefore, coarse sand filters are recommended for polishing the clarified effluent.

Sand Filtration

When sand filtration is used, coarse sand filter is often chosen because it is inexpensive to construct and simple to operate. Although dual media filtration with backwashing capability is a better technology, its high construction cost and the requirement of a more skilled operator (and therefore higher operation and maintenance cost) do not justify its use at Corps recreational areas. The design guidance for coarse sand filtration is provided later in this chapter.

Sludge Handling and Disposal

Regardless of the small size of the treatment plants in recreational areas, sludge handling and disposal can still be problem. Treatment of sludge is expensive, and sometimes disposal on-site is impossible. Hauling away the material for off-site disposal can be expensive, depending on distance. Some treatment plants "hide" the sludge handling/disposal problem -- as some operators do with the extended aeration and oxidation ditch systems -- by returning all sludge to the aeration tank or oxidation ditch so that the material is destroyed by endogenous respiration. These plants report no sludge removal for years. However, the practice is energy intensive because it is merely a version of aerobic sludge digestion that does not remove sludge from the aerator. At the same time, the practice creates a problem in the plant: inactive biomass builds up in the process, and the disperse-growth state of the biomass settles very poorly, so excessive solids leave the plant with the clarifier effluent. This problem has plagued many extended aeration treatment plants for municipal wastewater treatment and for recreational area wastewater treatment.

The practice of using the septic/equalization tank in existing recreational area treatment plants to store the biological solids generated by the RBC system is sound. Even the most conservative estimates indicate that without being cleaned, these tanks can store sludge produced over a period of 5 years or longer. This should simplify the plant operation and save on operation and maintenance costs.

Nuisances

Odor problems have not yet been reported for any of the RBC plants discussed in this report. Sulfate under septic conditions is reduced to sulfide, creating occasional odor problems at municipal sewage treatment plants. The source of sulfate is likely industrial and is not expected in recreational area sewage. Filter fly has never been a problem in operating RBC plants covered in this report.

Skill Level and Manpower Requirement

RBC systems require more skilled employees for operation than do simple treatment systems such as septic tank/leaching fields or lagoons (without aeration). The skill level required is the same for extended aeration/sand filters, facultative aerated lagoon/sand filters, facultative aerated lagoon/spray irrigation, oxidation ditch, and RBC-sand filters. Most States

would accept a level III operator for any of these treatment systems. In fact, the RBC system is the simplest mechanically to maintain and repair; it has only two motors (one drives the RBC shaft with a gear box; the other is for the clarifier/scoop unit). On the other hand, the extended aeration system has a compressor as well as an air-lift pump; an oxidation ditch uses a rotor cage motor plus a lift pump. Listed below are manpower requirements obtained from the survey of existing treatment plants in recreational areas:

	Manpower Requirements for 15,000 gpm <u>Design Flow</u>
Extended aeration/sand filters	3 hr/day
Facultative aerated lagoon/sand filters	1 hr/day
Facultative aerated lagoon/spray irrigation	1-1/2 hr/day
Oxidation ditch/sand filters	3 hr/day
RBC/sand filters	2 hr/day

First Cost (Equipment and Installation Plus 10 Percent Contingency)

Table 31 shows that the RBC/sand filters system has the highest first cost -- \$111,597, which is \$9449, or 9.3 percent, more than the oxidation ditch/sand filters; \$6109, or 5.8 percent, more than the facultative aerated lagoon/sand filters system; \$3597, or 3.3 percent, more than the extended aeration/sand filters system; and \$2096, or 1.9 percent, more than the facultative aerated lagoon/spray irrigation system. Note that land cost is not included in the estimate, and that only the RBC/sand filters system and the facultative aerated lagoon/spray irrigation system provide the designed level of nitrification with certainty.

Energy Consumption

As seen in Tables 25 through 30, the RBC/sand filters system at the 15,000 gpd design flow uses 13,800 kWh in one season (6 months).

This energy consumption is not significantly different from that of other alternatives -- except the extended aeration/sand filters system, which uses 8200 kWh more in one season. It is worth noting that this difference in power consumption can be greatly reduced if a septic/equalization tank is provided instead of an aerated equalization tank.

Operation and Maintenance Cost

The extended aeration/sand filters system and the oxidation ditch/sand filters system have the highest operations and maintenance costs because of their requirements for manpower and energy. The operation and maintenance cost of the RBC/sand filters is less (\$5310), whereas both lagoon systems have the lowest operation and maintenance costs. A difference of \$2000 to \$3000 in one season could be significant since the higher first cost for such a small treatment system can be recovered quickly.

System Failure

Many existing treatment plants in recreational areas have minor mechanical problems from time to time. One major concern in using RBC systems at Corps recreational areas is the structural integrity of the shaft and media of the RBC unit. Broken shafts, bearings, and media have been reported by municipal wastewater treatment systems.⁷

The causes of these failures are excess growth on the media due to organic overloading (beyond the design criteria), and structural weakness of the shafts and media -- possibly caused by manufacturing problems or shipping and installation damage. (In addition, there are many snails at the Fort Knox plant; this compounds the problem of excess weight on the shaft.)

These major difficulties have occurred so far only at municipal wastewater treatment plants; none of the RBC plants documented in this report has had major failures with shafts or media. However, one plant had to replace bearings after several years of operation. The oldest plant, Horse Shoe Camp, WV, has provided 10 years of uninterrupted service (in seasonal use) without such failures. Apparently, the suggested design procedure has to be followed to avoid organic overloading and the resulting shaft failure. The major RBC manufacturers are installing new and better shafts, and providing removable media so that segments of damaged media can be replaced easily without much interruption of plant operation. The record thus far for recreational area treatment plants seems to confirm the integrity of the RBC system.

Performance Guarantee

Many RBC manufacturers offer performance guarantees that generally provide a specified effluent with the equipment installed and operating at design conditions. The guarantee usually obligates the manufacturer to provide new equipment or a partial refund if the design effluent standards are not met. This guarantee depends on influent characteristics that are within specific limits. Generally, manufacturers are willing to negotiate a guarantee as long as they agree with the treatment system's design.

⁷ W. H. Chesnes et al., "Current Status of Municipal Wastewater Treatment With RBC Technology in the U.S.," in Proceedings of the 1st National Symposium/Workshop on RBC Technology, ed. Ed Smith et al., Vol 1 (1980), p 53; and ES Engineering Science, Sewage Treatment Plant Evaluation of Failure, Ft. Knox, KY (Report submitted to U.S. Army Corps of Engineers Huntsville Division Office, 1981).

5 RBC TECHNOLOGY SELECTION AND DESIGN GUIDANCE FOR CORPS RECREATIONAL AREAS

This chapter evaluates the usefulness of RBCs and other technologies for use at Corps recreational areas. In addition, the conditions under which RBCs should be selected for Corps recreational areas are described. Finally, the chapter provides preliminary design guidance on making RBCs total treatment systems -- from pretreatment to sludge handling.

Comparison of RBC With Other Treatment Technologies

The RBC-sand filtration system has the highest first cost of all alternatives presented. However, its operation and maintenance cost is lower than that of extended aeration/sand filters and oxidation ditch/sand filters. With RBCs, the lower first costs for extended aeration and oxidation ditch can be recovered in 2 years and 5 years, respectively. If each of the treatment alternatives has a 20-year useful life, the RBC system is less expensive in terms of total cost.

One advantage of the RBC system over the extended aeration and oxidation ditch systems is that a specified level of nitrification can be designed for. (Note that the preliminary design example in Chapter 4 shows a removal of $\text{NH}_3\text{-N}$ from 40 mg/L to 4 mg/L in cold weather -- early or late season.) While some nitrification takes place in the extended aeration and oxidation ditch systems, the level of nitrification, and therefore the effluent $\text{NH}_3\text{-N}$ concentration, is not under control because significant rate of sludge return of the mixed culture suppresses the active growth of nitrifying organisms. An additional consideration favoring the RBC system over the extended aeration or oxidation ditch system is the smaller amount of sludge to be removed at a less frequent rate.

The first cost and operation and maintenance cost of the RBC/sand filters system are higher than for either of the facultative/aerated lagoon systems. Therefore, an RBC system probably should not be chosen instead of a lagoon system unless land availability and cost are critical at the treatment plant site. In removing $\text{NH}_3\text{-N}$, the facultative/aerated lagoon and spray irrigation system is comparable to the RBC system, but the facultative/aerated lagoon and filter system is not.

The septic tank/leaching field's effluent quality is not comparable to that of other technologies, and the system's subsurface discharge has only limited use. However, when State approval can be obtained for areas where there are suitable percolation rates and no groundwater contamination problems, the septic tank/leaching field system is definitely the choice for recreational area use. It has the lowest first cost and lowest operation and maintenance cost. Highly skilled employees are not required; the system consumes almost no power.

Septic tank/leaching field system failure is common in household or commercial use. Given a proper design and the long resting period during the off-season, however, the chance of failure is not as high for recreational area application. Once a leaching field fails because of overloading, it is difficult and costly to replace or to rejuvenate it. Therefore, the leaching

field should be designed conservatively because the total cost of the system still would be much less than that for the other alternatives.

Selecting RBC Systems

Considering the total cost of treatment and impacts to the environment, the RBC/sand filters system is preferable to both the extended aeration/sand filters and the oxidation ditch/sand filters. In addition, the RBC/sand filters system should be chosen if the following conditions are met:

1. A septic tank/leaching field is not acceptable to the State regulating agency because of poor soil conditions or possible groundwater contamination.
2. Land availability or land cost prohibit the use of a facultative/aerated lagoon system.
3. Although land availability and land cost are not prohibitive with spray irrigation, controlled nitrification to provide a specified NPDES effluent $\text{NH}_3\text{-N}$ concentration is required, and freezing weather severely limits the use of the system. If designed nitrification is not required, the facultative/aerated lagoon and sand filter system, which is most cost-effective, should be chosen.

Step-by-Step Procedure for RBC Design

1. Use the procedure outlined in EM 1110-2-501 to estimate flow rates.
2. Determine the capacity of the septic/equalization tank by using the mass flow analysis based on a week's flow in peak season (procedure in EM 1110-2-501), and add 25 percent to this capacity for sludge storage.
3. Determine the size of the RBC unit.
 - a. Assume 40 percent BOD removal in the septic/equalization tank.
 - b. Assume 90 to 95 percent of the remaining BOD is soluble.
 - c. Add 40 mg/L more soluble BOD to the septic tank effluent because of sludge solubilization in the septic tank.
 - d. For nitrification to take place, soluble BOD has to be reduced to 15 mg/L. Assume a summer sewage temperature, and using either design curves or tables determine the allowable hydraulic loading. (See, for example, Figures 19 through 22 and Tables 32 and 33.)
 - e. Assume 40 mg/L $\text{NH}_3\text{-N}$ in the RBC influent (unless more accurate data are available). From the NPDES permit, use the specific effluent $\text{NH}_3\text{-N}$ concentration in summer. Again, either design curves or tables can be used to determine the hydraulic loading requirement for nitrification. The temperature correction for nitrification should be obtained from the manufacturer's manuals.

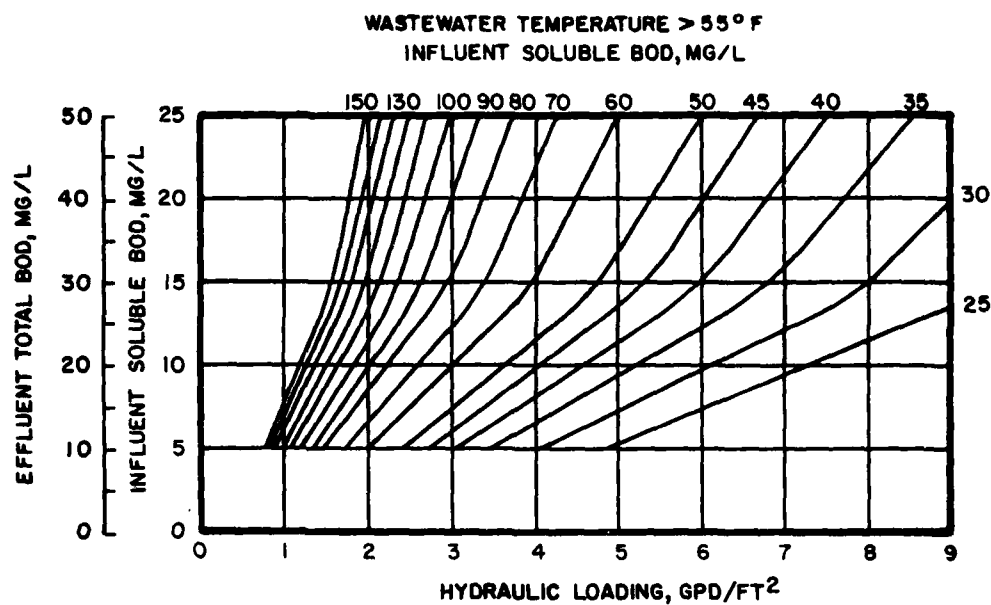


Figure 19. Design curves for BOD removal: Autotrol (from Wastewater Treatment System: Autotrol Corp. Design Manual [Autotrol Corp., 1979]).

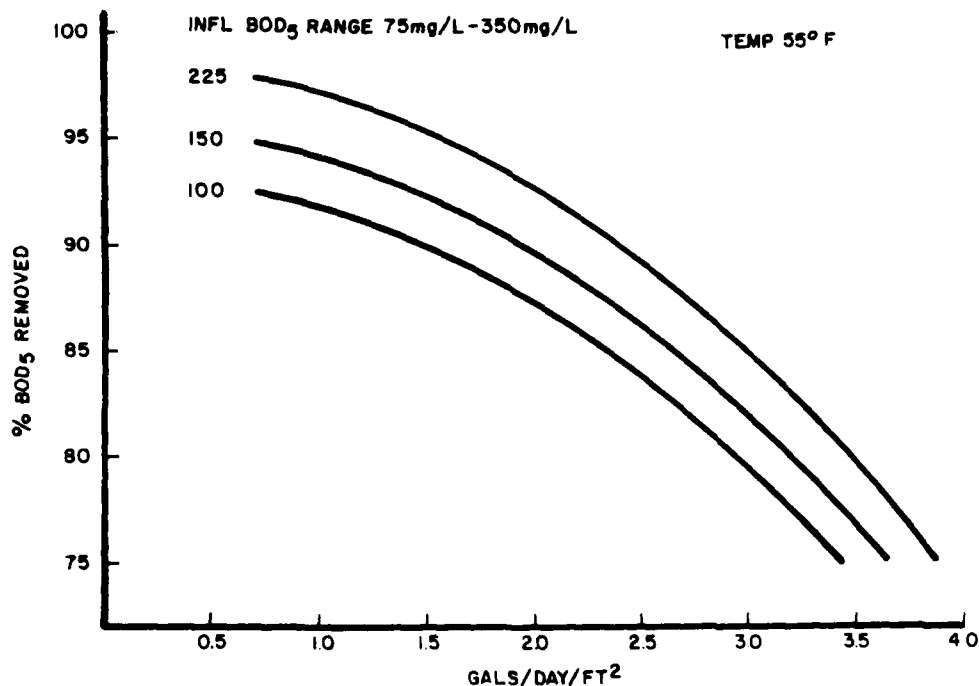


Figure 20. Design curves for BOD removal: Hormel (from George A. Hormel & Company, Catalog Sheet 10.130).

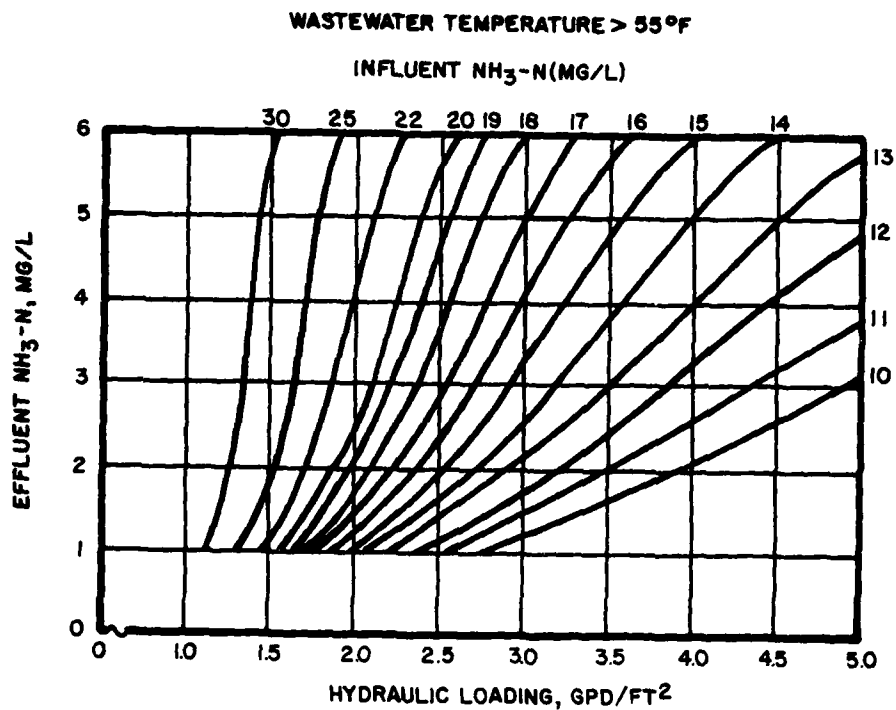


Figure 21. Design curves for $\text{NH}_3\text{-N}$ removal: Autotrol (from Wastewater Treatment System: Autotrol Corp. Design Manual [Autotrol Corp., 1979]).

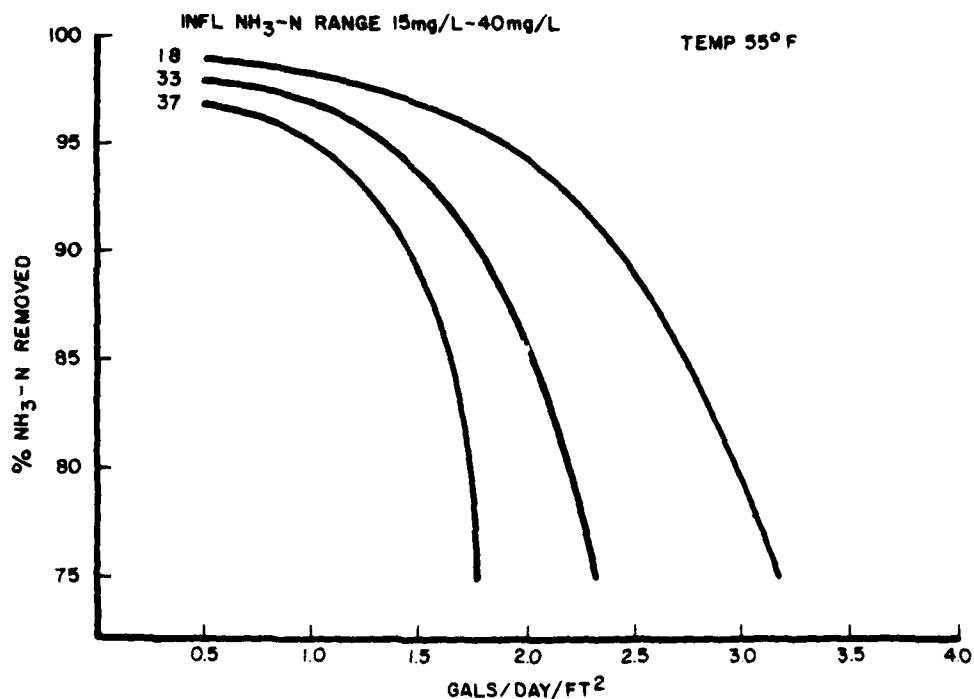


Figure 22. Design curves for $\text{NH}_3\text{-N}$ removal: Hormel (from George A. Hormel & Company, Catalog Sheet 10.130).

Table 32

Soluble BOD Loading Rates (Clow Corp.)

<u>Design Effluent Soluble BOD Concentrations, mg/L</u>	<u>Soluble BOD Application Rate, lb/1000 sq ft-day</u>
5	1
10	1-1/2
15	2
20	2-1/4
25	2-1/2
30	2-3/4

Table 33

Nitrification Loading Rates, Clow Corp.
(for Approximate and Preliminary Sizing)

<u>Design Effluent NH₃-N Concentration, mg/L</u>	<u>Loading Rate (Influent 10 to 30 mg/L), lb NH₃-N/1000 sq ft-day</u>
1	0.23 - 0.27
2	0.30 - 0.32
3	0.33 - 0.40
4	0.35 - 0.45
5	0.36 - 0.50
6	0.38 - 0.58
7	0.43 - 0.65
8	0.50 - 0.70

- f. Combine the allowable hydraulic loadings obtained from steps d and e.
- g. Repeat steps d and e using the winter sewage temperature and the effluent NH₃-N concentration allowable in winter; then determine the combined hydraulic loading for BOD removal and nitrification.
- h. From steps f and g, select the larger media area requirements to use in the design.
- i. Select the proper model of RBC from the manufacturer's manual (choose a three-stage or four-stage model).
- j. Expand the first stage of a four-stage model by removing the partition between the first and the second stages; this procedure is recommended by some RBC manufacturers for treating septic sewage.
- k. If the alkalinity requirement of 7.2 g of CaCO₃ per gram of NH₃-N removal is not satisfied, provide pH adjustment and alkalinity addition to ensure success of nitrification.

1. Use 300 to 600 gpd/sq ft and the design flow rate (equalized) to determine the surface area requirement of the RBC clarifier.

4. The alternating filter dosing tank in the RBC system doses two filters while the third is resting. Assume four doses per filter per day for this intermittently operated coarse sand filter. The working volume of the dosing tank in gallons is determined by dividing the design flow gallons per day by eight (two filters x four doses/filter-day).

5. The area required for each coarse sand filter can be calculated by dividing the volume per dose (or the working volume of the dosing tank) by the allowable depth of sewage applied per dose (4-in. depth is recommended). Check the rate of application in gal/sq ft-day to the filters. A rate of application of 12/gal/sq ft-day is acceptable. Beyond this rate, the filter size can be increased to adjust the rate of application to 12 gal/sq ft-day.

For sand media, an effective size of 0.3 mm to 0.5 mm and a uniformity coefficient of 4.0 or less would be appropriate. Thirty inches of sand on top of 9 to 12 in. of coarse aggregate and a perforated PVC underdrain are recommended.

6. The capacity of the chlorine contact tank is determined by the required contact time specific by State regulations, generally 30 minutes at average daily flow rate and 20 minutes at maximum daily flow rate. Depth of the contact tank should be 3 to 4 ft. The tank should be partitioned to provide channel flow so that short-circuiting can be minimized.

6 SUMMARY

This report has provided selection criteria, case histories, and design information useful to Civil Works personnel who must decide whether to use RBC technology at Corps recreational areas. In addition, this report has presented guidance that Civil Works pollution abatement engineers can use to ensure that RBC operation is both economical and compatible with the Corps' needs.

METRIC CONVERSION FACTORS

$^{\circ}\text{C} = 5/9 (^{\circ}\text{F}-32)$
1 in. = 25.4 mm
1 ft = 0.3048 m
1 sq ft = 0.0929 m^2
1 cu ft = 0.0283 m^3
1 gal = 4.545 L
1 mgd = 3785.0 kL/day
1 lb = 0.373 kg
1 psi = 6.9 kPa
1 pt = 0.55 L
1 Q = 1.136 L
1 kW = 14.34 kg-cal/min
1 kWh = 3.6 MJ

AD-A116 759

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APR 82 E D SMITH, C P POON, J CULLINANE
CERL-TR-N-126

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APPENDIX:

SURVEY QUESTIONNAIRE SENT TO
CORPS DISTRICT OFFICES

Questionnaire on:

Corps of Engineers' Recreational Area Sewage Treatment Facilities
(please use extra sheets if you need more space for your answers)

1. Prevalant form of treatment system in recreational areas

<u>Treatment Systems</u>	<u>Number of Installations</u>
Septic tank and leaching field	
Lagoon with sand filters	
without sand filters	
Extended aeration	
Trickling filters	
Land treatment	
Oxidation ditch	
Others (please specify)	

2. Recreational area facilities

Facility	Seasonal or Year- round Use	No. in Use	No. in Planning	Number of Sites Which Have the Following		
				Toilet Dumping Station	Shower	Laundry
Camping						
Swimming						
Boating						
Picnic						
Combination						
Others (specify)						

3. Sewage characteristics

Please provide any survey data of sewage characteristics at any of your recreational sites.

Sewage Flow Rates

Treatment Facility	Weekdays	Weekends	Holidays	Off- Season	Per Person Basis
-----------------------	----------	----------	----------	----------------	------------------------

Influent sewage characteristics

Concentration of

Treatment Facility	BOD	Soluble BOD	SS	Nitrogen	Other
-----------------------	-----	----------------	----	----------	-------

Describe concentration variation of any of the parameters listed above, if known.

3. continued

Effluent characteristics:

Concentration of					
Treatment Facility	BOD	COD	SS	Nitrogen	Others

Effluent standards by regulating agency:

4. Operation and maintenance

Any startup problems?

Any problem with sewage load fluctuations?

Man-hour/week or month

Power requirement (electricity and/or fuel) kWh/month or unit flow

Any system failure (describe)?

How to keep system going at low or no flow?

Any adverse effect of cold weather?

Quantity of sludge

Any sludge treatment?

Sludge disposal (on-site? off-site? how often hauled away?)

Vandalism protection

Any winterizing problem (shut down)?

5. Cost

Capital cost (year)

Operation and maintenance cost (including power and chemicals, etc.)

6. Treatment facility planning

Any plan to expand or add to existing facilities, or additional treatment requirements?

What treatment technology is planned for expansion or new facilities?

7. Present mechanism used to choose wastewater treatment technologies/techniques by your CE district office.

8. What information (regulations, ETL's, ETN's engineering manuals, etc.) is currently available to assist your office in choosing wastewater treatment strategies?

9. What qualitative and quantitative information do you require for designing your CE recreational area sewage treatment facilities (number of visitors, flow fluctuation, state effluent requirements, etc.)

10. Do you plan to use RBC for sewage treatment in your recreational areas? Please state reasons for using or not using it.

11. If you already have an RBC facility in your recreational area:

Why was RBC chosen over the other technology?

Who designed the facility?

Design procedure followed manufacturer's manual or your own criteria?

12. RBC operation and maintenance

Any startup problems?

Any problem with sewage load fluctuations?

Man-hour/week or month

Power requirement

Any system failure (media or mechanical or structural)?

How to keep system going at low or no flow?

Any adverse effect of cold weather?

Meeting the State effluent standards?

Quantity of sludge production

Sludge settling characteristics

Any sludge treatment?

How is sludge disposed of?

Vandalism problem

Any winterizing problem (shutdown)?

Identify the RBC manufacturer or supplier

Did the manufacturer provide assistance in startup and training of operation?

When was the facility installed?

Capital cost

Installation cost

Operation and maintenance cost, including power and chemicals, etc.

If you had a choice to do it over again, would you choose RBC, and why?

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